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PHASE I REPORT

RESULTS OF SCREENING ANALYSES OF 224 CALIFORNIA MSW LANDFILLS

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1 Executive Summary/Introduction

This report presents the results of work completed by GeoSyntec Consultants, Inc. (GeoSyntec) and its subcontractors under Task 3 of the Landfill Facility Compliance Study for the California Integrated Waste Management Board (CIWMB). Phase I includes Tasks 1–3 (compiling a checklist of pertinent environmental regulatory requirements, developing a cross-media database inventory of 224 California municipal solid waste (MSW) landfills, and assessing MSW landfill environmental performance for the time period from January 1998 through December 2001). Phase II consists of Tasks 4–8 (these tasks include assessing the effectiveness of current regulatory requirements in controlling environmental impacts over time).* The following items are actions taken to satisfy requirements in the Task 3 scope of work:

- Categorize California's MSW landfills with respect to various quantifiable site characteristics, including liner type, site status, physical setting, and average annual precipitation.
- Develop screening criteria for evaluating the environmental performance of MSW landfills.
- Perform analyses of the site characteristic categories, summarizing by category (not specific landfills), the environmental performance (i.e., regulatory compliance) of the landfills. Analyses would include evaluating any commonality of factors pertaining to the environmental performance of the landfills.
- Recommend 40 MSW landfills for inclusion in the Phase II assessment.
- Provide a brief overview of solid waste landfills in California that do not receive MSW.

The emphasis of this report is to perform statistical analyses that help one understand the relationship between various factors that are assumed to be "independent" (for example, owner type or social setting) and conditions that reflect environmental performance of the sites ("dependent" factors). For this study, it has been assumed that environmental performance of the site can be represented by the number of regulatory actions imposed on the site, such as in regard to monitoring status of the site. Detailed statistical analyses are preformed to evaluate the relationship between various dependent and independent factors and to test the assumptions made in the analyses.

1.1 Background Data Collection

The analyses presented in this report were conducted using the information collected for and contained in the relational database completed as part of Task 2 of this project. In accordance with the Task 2 scope of work, GeoSyntec compiled a database inventory of 224 California MSW landfills for the CIWMB. The 224 California MSW landfills included as part of Task 2 were those that accepted waste since October 9, 1993. This date was chosen as the cutoff date, since it was the effective date for Part 258 of Title 40 of the Code of Federal Regulations (40 CFR 258), also known as Subtitle D, which was the first comprehensive federal standard for MSW landfills.

The information on the 224 MSW landfills in the database includes general site characteristics (for example, owner type, age, size, social setting, and liner type) and environmental performance information collected during the period from January 1, 1998, to December 31, 2001. (The timeframe was initially shorter, but was extended to incorporate comments received from owners and operators

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* A description of the Landfill Facility Compliance Study and progress updates may be found on the CIWMB's Web site at www.ciwmb.ca.gov/Landfills/.

during the first comment period, described in section 1.1.1.) Any changes that occurred after December 31, 2001, are not reflected in this report.

The database included information gathered by GeoSyntec during file reviews at each regional water quality control board (RWQCB), enforcement agency (EA), and air quality management/air pollution control district (AQMD/APCD) office from September 2000 through May 2001. Sources for the collected data were referenced throughout the database. In accordance with the approved scope of work and budget, the time allotted to collect all information was limited and had to be divided between the RWQCB office, the EA office, and the AQMD/APCD office. GeoSyntec submitted the first draft database to the CIWMB in September 2001.

Recognizing the limitations of the relatively brief file review period, the CIWMB forwarded the database information first to the respective landfill owners and operators and later to regulators, requesting verification, comments, and corrections regarding each site, as appropriate.

To finalize the database, there were two separate comment periods. The first comment period was open for owner and operator comments (Section 1.1.1). The second comment period was open for owner, operator, and regulator comments (Section 1.1.2).

1.1.1 Review and Comment Period One

During the first comment period, the owners and operators were requested to submit their comments and corrections to the CIWMB by November 26, 2001. A total of 111 sets of comments was received by the CIWMB during this first period. These comments were then forwarded to GeoSyntec via e-mail. Owner/operator comments continued to be received for four months following the November 26, 2001 deadline. GeoSyntec reviewed the owner/operator comments forwarded by the CIWMB through March 25, 2002 and incorporated them, as appropriate, in the database.

GeoSyntec recognized that even with the addition of owner and operator comments, gaps in the data existed. In late 2001, GeoSyntec asked each RWQCB to confirm the monitoring status for the sites within its jurisdiction. By the end of January 2002, each RWQCB had provided the monitoring status for each of its sites on the database. In some cases, the monitoring status provided by the RWQCB conflicted with the information provided by the owners and operators. The CIWMB then contacted the affected owners to provide them with another opportunity to comment.

After resolution of owner/operator comments on the monitoring status, GeoSyntec submitted a second draft of the database to CIWMB on May 14, 2002.

1.1.2 Review and Comment Period Two

As the initial Task 3 analyses of the database were conducted, it was found that even with the addition of owner and operator comments, there were still some gaps in the data. As a result, CIWMB staff reviewed its in-house library of landfill documents and worked with the State Water Resources Control Board (SWRCB) to fill these gaps. This review included the use of the CIWMB's Solid Waste Information System (SWIS) database to obtain EA inspection findings and enforcement actions.

Once these items were included, the CIWMB forwarded the draft database to each owner, operator, RWQCB, EA, and AQMD/APCD for comment. Each party was requested to submit its comments and corrections to the CIWMB by November 12, 2002. A total of 126 sets of comments was received by the CIWMB during this second comment period. These comments were then forwarded to GeoSyntec via mail or e-mail. Owner, operator, and regulator comments continued to be received for two months following the November 12, 2002, deadline. GeoSyntec reviewed the owner, operator, and regulator comments forwarded by the CIWMB through January 23, 2003, and incorporated them, as appropriate, in the final database.

1.1.3 Final Database

The final database was submitted to the CIWMB on February 4, 2003. On April 7. 2003, the CIWMB posted the final data inventory on its Web site at www.ciwmb.ca.gov/Landfills/ComplyStudy/db/.

While substantial efforts have been made to ensure the correctness and completeness of the data within the database, there are still undoubtedly errors in the dataset. As with any undertaking of this magnitude, some errors in measurement, interpretation, and data entry are inevitable. However, as the findings of the screening analyses presented in this report do not depend upon any single record but represent statistical analyses of a larger body of data, these findings are considered reliable with a relatively high level of confidence.

1.2 Report Organization

Section 2 of this report presents a brief overview of each of the landfill site characteristics used in the environmental performance analyses of the 224 MSW landfills contained in this study, including the liner type, site status, physical setting, and average annual precipitation. At the same time, this information provides the reader a snapshot of the state of landfill design and operation for the time of the study, January 1998 through December 2001.

Section 3 presents the screening methodology used to evaluate the relationships between each landfill site characteristic and environmental performance for the data contained in the database. It describes the selection and classification of the data and the statistical methods used to evaluate possible relationships.

Section 4 summarizes the results of the environmental performance screening analyses by each landfill site characteristic.

Section 5 summarizes the results of multiple variable analyses of landfill site characteristics, including:

- A profile of a “typical” landfill.
- A brief overview of the design and operational characteristics of urban, suburban, and rural landfills.
- A review of the environmental performance for urban, suburban, and rural landfills by multiple landfill site characteristics.
- A review of the environmental performance for active, inactive, closed, and combination landfills by multiple site characteristics.

Conclusions from the screening analyses are presented in Section 6.

The 40 MSW landfills selected for the Phase II portion of the study are presented in Section 7.

In addition to analyses of the 224 MSW landfills, a brief overview is provided in Appendix A on eight solid waste landfills that do not receive MSW. The purpose of this overview is to advise the reader of another set of solid waste landfills that are not addressed by the contracted study.

The results of the screening analyses of the 224 MSW landfills, including summary tables and charts, are included in Appendices B-2 through D-1.

2 MSW Landfill Site Characteristics Used in Analyses

2.1 Introduction

This section presents a brief overview of each of the landfill site characteristics used in the environmental performance analyses of the 224 MSW landfills contained in this study. At the same time, this information provides the reader a snapshot of the state of landfill design and operation for the time of the study, January 1998 through December 2001. The following landfill site characteristics were selected to provide a cross-environmental media view for the analysis of environmental performance:

1. Owner type.
2. Landfill age.
3. Landfill size.
4. Social setting.
5. Physical setting.
6. Underlying geologic material.
7. Minimum depth to underlying groundwater.
8. Average annual precipitation.
9. Liner type.
10. Final cover type.
11. Landfill gas collection system.
12. Site status.
13. Fill method.

Each site characteristic is described and broken down into appropriate sub-components (that is, categories). For the 224 landfills contained in the study, a distribution is provided for each site characteristic showing the number of landfills in each category. The distribution shows the percentage of the 224 landfills this represents. For example, the Social Setting site characteristic is divided into three categories (urban, suburban, and rural). The distribution shows that for the 224 landfills, 71 are urban (31.7 percent), 14 are suburban (6.3 percent), and 139 are rural (62.1 percent). The distribution data is derived from the information contained in the Task 2 database and covers January 1998 through December 2001.

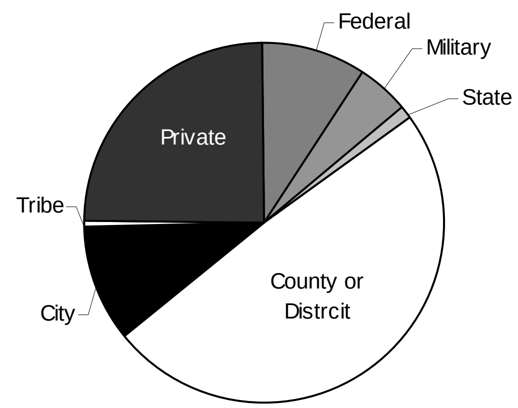
2.2 Landfill Site Characteristics

2.2.1 Owner Type

During the data collection, seven different ownership categories were identified, including federal, military, State, county or district, city, tribe, and private. The county or district category has the largest number of sites with approximately 49 percent of the total. The distribution of owner type is shown in Figure 2.1.

Figure 2.1: Distribution of Owner Type

Owner Type	Number of Landfills	Percent of Total
Federal	21	9.4
Military	11	4.9
State	2	0.9
County or district	109	48.7
City	24	10.7
Tribe	1	0.4
Private	56	25.0
Total	**224**	**100**



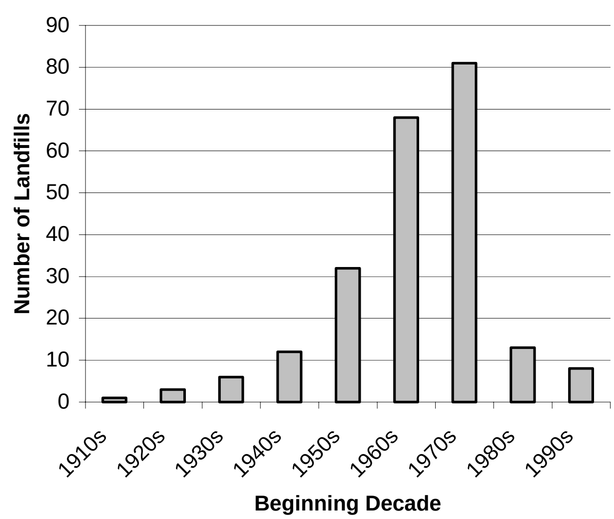
Grouping all public entities, 168 sites, or 75 percent, have public ownership and 56 sites, or 25 percent, have private ownership.

2.2.2 Landfill Age

The landfill age was estimated based on the reported date that the landfill first began receiving waste. The oldest landfill in the study began receiving waste in 1917; the youngest, in 1995. The mean year of first receipt of waste is 1965. By decade, the 1970s had the highest number of beginning landfill operations with 81, or 36 percent of the total. Figure 2.2 shows the distribution decade in which landfills began receiving waste.

Figure 2.2 Distribution of Landfill Age

Beginning Decade	Number of Landfills	Percent of Total
1910s	1	0.4
1920s	3	1.3
1930s	6	2.7
1940s	12	5.4
1950s	32	14.3
1960s	68	30.4
1970s	81	36.2
1980s	13	5.8
1990s	8	3.6
Total	**224**	**100**



2.2.3 Landfill Size

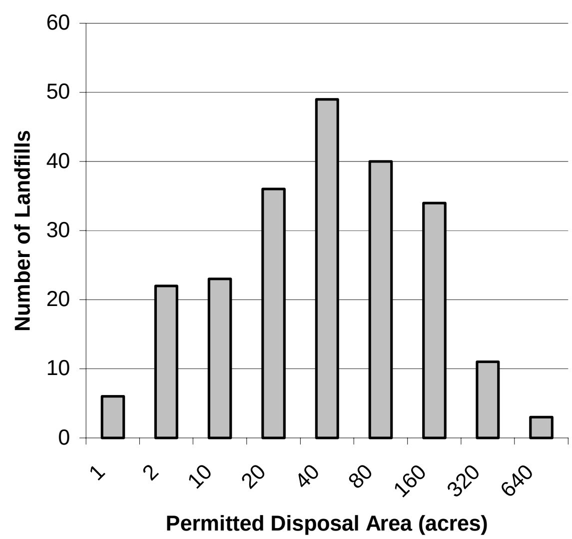
The size of the landfills was categorized based on four different data sets, as follows:

1. Permitted disposal area in acres.
2. Permitted disposal volume in cubic yards.
3. Permitted maximum daily tonnage.
4. Estimated remaining capacity in cubic yards.

Permitted disposal area is the plan area of the landfill property that is permitted, generally by the solid waste facilities permit (SWFP) for the disposal of solid waste. This area is often referred to as the permitted waste footprint. The permitted disposal areas ranged from 1 acre to 800 acres. The average permitted area was 105 acres and the median was 55.5 acres. The distribution of permitted disposal area is shown in Figure 2.3.

Figure 2.3 Distribution of Permited Disposal Area

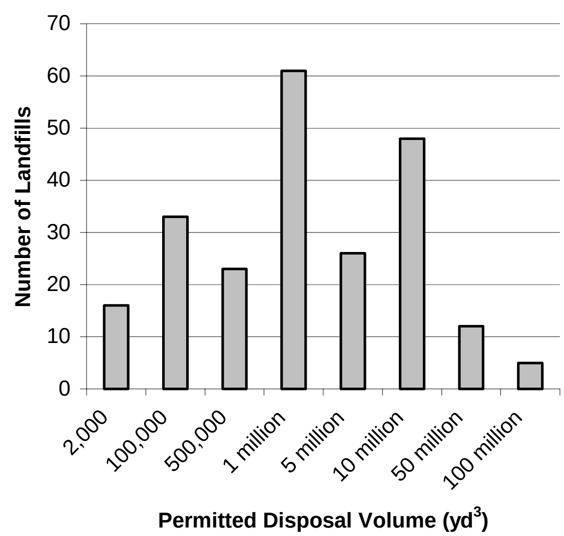
Permitted Disposal Area (Acres)	Number of Landfills	Percent of Total
1–1.9	6	2.7
2–9.9	22	9.8
10–19.9	23	10.3
20–39.9	36	16.1
40–79.9	49	21.9
80–159.9	40	17.9
160–319.9	34	15.2
320–639.9	11	4.9
640 or more	3	1.3
Total	**224**	**100**



Permitted disposal volume is the total volume of the landfill space that is permitted (generally by the SWFP) for the disposal of solid waste. This volume is often referred to as the site capacity. The permitted disposal volume ranged from 2,100 cubic yards to approximately 185 million cubic yards. The median volume was 2.7 million cubic yards. The distribution of permitted disposal volume is shown in Figure 2.4.

Figure 2.4: Distribution of Permited Disposal Volume

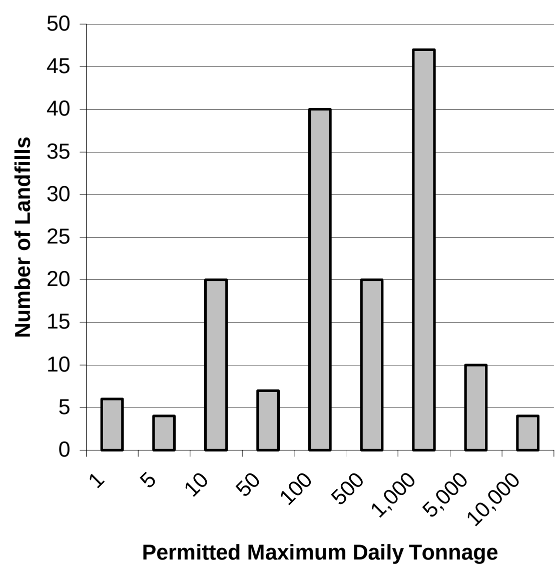
Permitted Disposal Volume (yd^3)	Number of Landfills	Percent of Total
2,000–99,000	16	7.1
100,000–499,000	33	14.7
500,000–990,000	23	10.3
1 million–4.9 million	61	27.2
5 million–9.9 million	26	11.6
10 million–49 million	48	21.4
50 million–99 million	12	5.4
100 million or more	5	2.2
Total	**224**	**100**



Permitted maximum daily tonnage is the tonnage of solid waste that is permitted (generally by the SWFP) to be disposed per day at the landfill. This standard can be waived by the CIWMB when a local emergency or state of emergency has been officially proclaimed. For this analysis, only the 158 active or partially active sites were included. For the closed and inactive sites, the daily tonnage is effectively zero. The permitted maximum daily tonnage for the time frame of the study ranged from 1 ton to 13,200 tons. The median tonnage was 385 tons. For the entire state, the permitted maximum daily tonnage was approximately 195,500 tons, which equates to approximately 11.5 pounds of MSW per person per day. The distribution of permitted disposal volume is shown in Figure 2.5.

Figure 2.5: Distribution of Permited Maximum Daily Tonnage (Active Sites Only)

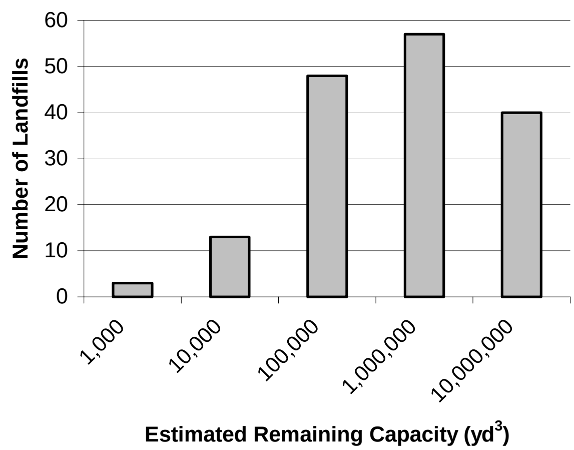
Permitted Maximum Daily Tonnage (tons)	Number of Landfills	Percent of Total
1–4.9	6	3.8
5–9.9	4	2.5
10–49	20	12.7
50–99	7	4.5
100–490	40	25.3
500–990	20	12.7
1,000–4,900	47	29.7
5,000–9,900	10	6.3
10,000 or more	4	2.5
Total	**158**	**100**



Estimated remaining capacity is the reported portion of the permitted disposal volume that has not yet been filled with solid waste. This data came from many sources, including financial assurance reporting, permits, closure plans, and periodic site reviews. For this analysis, only the 158 active or partially active sites were included. The remaining capacity is effectively zero for the closed and inactive sites. The remaining capacity for the landfills during the time frame of the study ranged from approximately 2,000 cubic yards to approximately 95 million cubic yards. The median remaining capacity was 2,153,800 cubic yards. For the entire state, the total remaining capacity was approximately 1.2 billion cubic yards, which equates to approximately 35 cubic yards per person. This is roughly equivalent to a cube that is 10 feet by 10 feet by 10 feet. The distribution of estimated remaining capacity is shown in Figure 2.6.

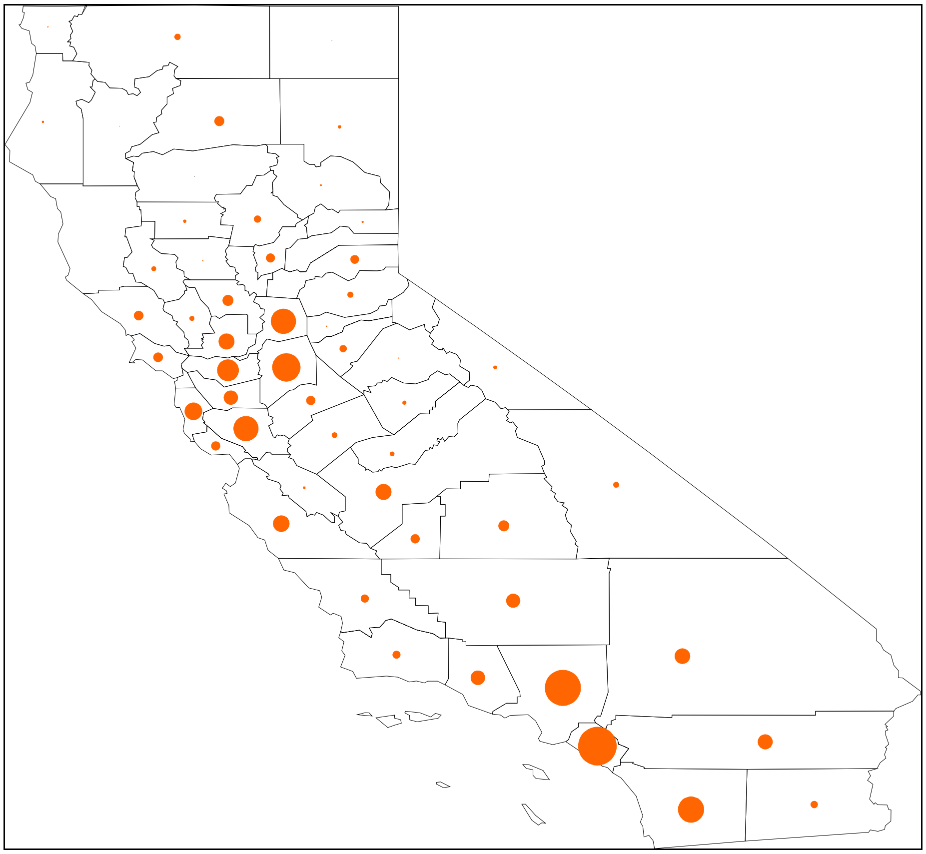
Figure 2.6: Distribution of Estimated Remaining Capacity (active sites only)

Estimated Remaining Capacity(yd^3)	Number of Landfills	Percent of Total
1,000–9,900	2	1.3
10,000–99,000	13	8.2
100,000–990,000	46	29.1
1 million–9.9 million	56	35.4
10 million or more	41	26.0
Total	**158**	**100**



In general, California's remaining capacity for the time frame of the study was concentrated around the population centers (may include surrounding counties) of Los Angeles, San Francisco, Sacramento, and San Diego as shown in Figure 2.7. In this figure, the area of each dot is proportional to the county's remaining capacity.

Figure 2.7: Geographic Distribution of Estimated Remaining Capacity (active sites only)



Based on the Task 2 database information gathered for the period from January 1, 1998, to December 31, 2001, the following nine counties had no remaining MSW capacity: Alpine, Mendocino, Modoc, Nevada, San Francisco, Sutter, Tehama, and Trinity. Between 2001 and the date of this report, additional landfills have closed or become inactive. This created an additional three counties with zero remaining capacity, including Del Norte, Humboldt, and Tuolumne. Note that these estimates of remaining capacity do not include the capacity of proposed landfills that had not received waste as of December 3, 2001.

2.2.4 Social Setting

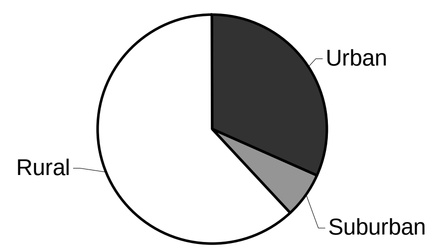
The categorization for social setting was based on the population density around the landfill. For this study, the following three categories were used based on U.S. Census Bureau's Census 2000 ZIP Code Tabulation Areas and census tract data files:

1. **Urban:** Includes areas with 50,000 or more people. The urban area data was obtained from http://www.census.gov/geo/www/cob/ua_metadata.html.
2. **Suburban:** Includes census tracts with 25,000 to 50,000 people. The 2000 census tract data was obtained from the Environmental Systems Research Institute.
3. **Rural:** Includes census tracts with fewer than 25,000 people.

The "Rural" category had the largest number of sites with approximately 62.1 percent of the total with 139 landfills. Figure 2.8 presents the distribution of social setting.

Figure 2.8: Distribution of Social Setting

Social Setting	Number of Landfills	Percent of Total
Urban	71	31.7
Suburban	14	6.3
Rural	139	62.1
Total	**224**	**100**



2.2.5 Physical Setting

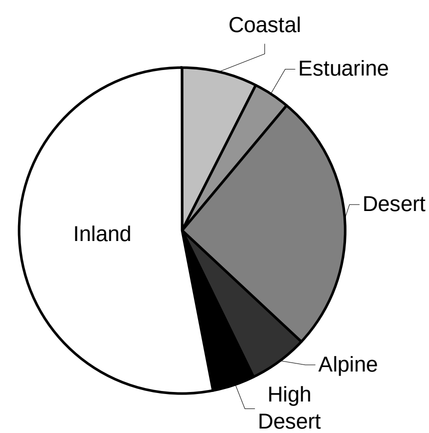
The physical setting of the landfills was categorized based on certain topographic and climatologic characteristics. For this study, the following six categories were used:

1. **Coastal:** Between the ocean and first major ridge of mountains.
2. **Estuarine:** Along a bay/estuary.
3. **Desert:** Where less than 10 inches (25.4 millimeters) of precipitation per year are normally received as rain.
4. **Alpine:** Higher than 5,000 feet (1,524 meters) above mean sea level and/or where more than 50 percent of the annual precipitation is normally received as snow.
5. **High Desert:** Where both desert and alpine criteria are met.
6. **Inland:** All other locations that do not meet the above criteria.

The inland category had the largest number of sites with approximately 53 percent of the total with 119 landfills. Figure 2.9 presents the distribution of physical setting.

Figure 2.9: Distribution of Physical Setting

Physical Setting	Number of Landfills	Percent of Total
Coastal	17	7.6
Estuarine	8	3.6
Desert	58	25.9
Alpine	13	5.8
High Desert	9	4.0
Inland	119	53.1
Total	**224**	**100**



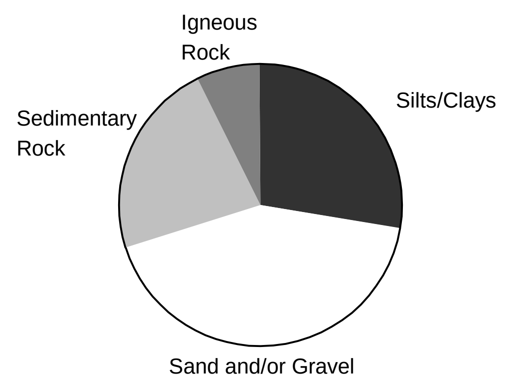
2.2.6 Underlying Geologic Material

The categorization for underlying geologic material was based on the type of native earthen material located beneath waste in landfills. For this study, the following four categories were used: silts/clays, sand and/or gravel, sedimentary rock, and igneous rock. When more than one type of geologic material was identified below a landfill, the predominant material was reported.

The "Sand and/or Gravel" category had the largest number of sites, 95 landfills (approximately 42.4 percent of the total). Figure 2.10 presents the distribution of underlying geologic material.

Figure 2.10: Distribution of Underlying Geologic Material

Geologic Material	Number of Landfills	Percent of Total
Silts/Clays	62	27.7
Sand and/or Gravel	95	42.4
Sedimentary Rock	51	22.8
Igneous Rock	16	7.1
Total	**224**	**100**

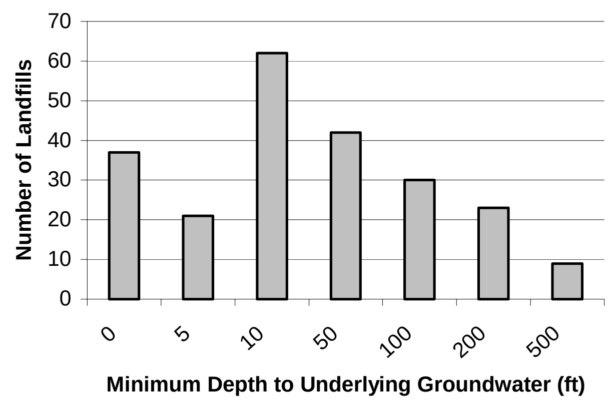


2.2.7 Minimum Depth to Underlying Groundwater

Title 27 of the California Code of Regulations (27 CCR) (Division 2, Subdivision 1, Chapter 2) defines underlying groundwater as "…water which rises above the zone of saturation due to capillary forces." The reported minimum distance between waste and underlying groundwater ranged from zero to more than 1,000 feet. The median depth to groundwater was 34.5 feet. The distribution of minimum depth to underlying groundwater is shown in Figure 2.11.

Figure 2.11: Distribution of Minimum Depth to Underlying Groundwater

Minimum Depth (ft)	Number of Landfills	Percent of Total
0–4.9	37	16.5
5–9.9	21	9.4
10–49	62	27.7
50–99	42	18.8
100–199	30	13.4
200–499	23	10.3
500 or more	9	4.0
Total	**224**	**100**

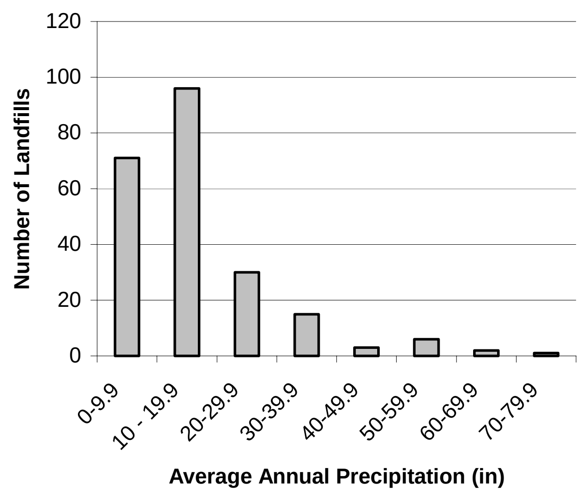


2.2.8 Average Annual Precipitation

The reported average annual precipitation ranged from 2 inches to 74 inches. The mean annual precipitation was 16 inches. The distribution of average annual precipitation is shown in Figure 2.12.

Figure 2.12: Distribution of Average Annual Precipitation

Average Annual Precipitation (in)	Number of Landfills	Percent of Total
0–9.9	71	31.7
10–19.9	96	42.9
20–29.9	30	13.4
30–39.9	15	6.7
40–49.9	3	1.3
50–59.9	6	2.7
60–69.9	2	0.9
70–79.9	1	0.4
Total	**224**	**100**



2.2.9 Liner Type

Landfills can consist of one or more waste management units (WMU), where waste is disposed. The containment system for each WMU can be divided into four primary categories as follows:

1. **Fully Lined Subtitle D:** Includes landfills in which all of the WMUs at a landfill are entirely lined in accordance with the design requirements in the CFR (40 CFR 258) for a liner system. This category includes those sites with an approved engineered alternative to the Subtitle D prescriptive standard (such as a geosynthetic clay liner in lieu of a compacted clay liner.) Note that disposal areas that pre-date Subtitle D are not required to have Subtitle D liners.
2. **Fully Lined–Partially Non-Subtitle D:** Includes landfills in which all of the WMUs are entirely lined but with at least one portion of a WMU with a liner that does not meet the Subtitle D design standards.
3. **Partially Unlined:** includes those landfill with a minimum of one portion (or WMU) with a liner and one portion (or WMU) without one.
4. **Fully Unlined:** Includes landfills whose WMUs are without any liner.

The "Fully Unlined" category had the largest number of sites, with approximately 62 percent of the total (138 landfills). Figure 2.13 presents the distribution of liner types for all 224 landfills. Note that if closed and inactive sites are excluded from this tally, fully unlined sites are reduced to approximately 52 percent of the total. The distribution of liner type for the active landfills is included in Figure 2.14.

Figure 2.13: Distribution of Liner Types (All 224 Landfills)

Liner Type	Number of Landfills	Percent of Total
Fully Subtitle D	4	1.8
Fully Lined—Partially non-Subtitle D	12	5.4
Partially Unlined	70	31.3
Fully Unlined	138	61.6
Total	**224**	**100**

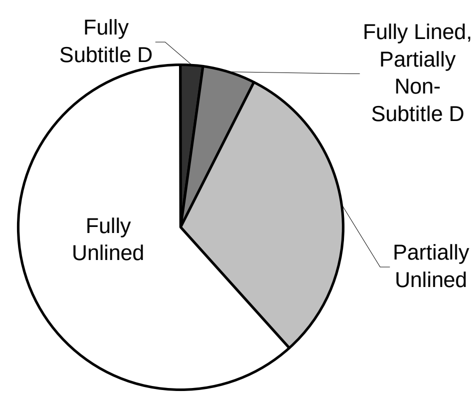
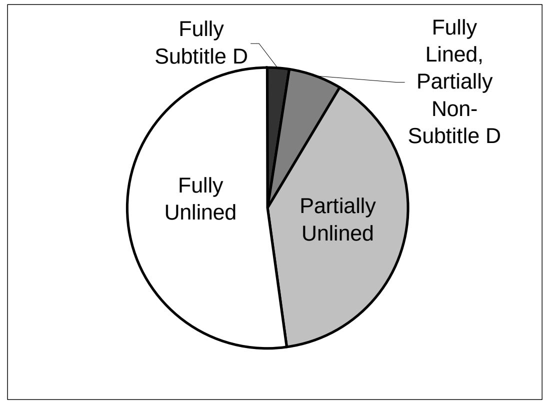


Figure 2.14: Distribution of Liner Types (Active Sites Only)

Liner Type	Number of Landfills	Percent of Total
Fully Subtitle D	4	2.5
Fully Lined—Partially Non-Subtitle D	10	6.3
Partially Unlined	62	39.3
Fully Unlined	82	51.9
Total	**158**	**100**



The four fully Subtitle D-lined landfills are:

1. Keller Canyon Landfill.
2. Norcal Waste Systems Ostrom Road Landfill, Inc.
3. Sunshine Canyon Sanitary Landfill County Extension.
4. CWMI Kettleman Hills Facility (however several non-Subtitle D impoundments exist on-site).

2.2.10 Final Cover Type

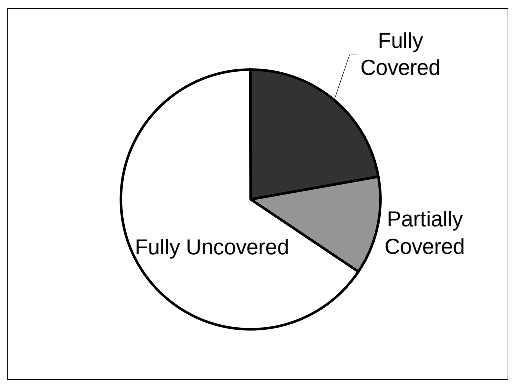
The status of final cover systems at each landfill was recorded. Future planned cover construction was not included and only existing final covers were reported. Since landfills can consist of one or more WMU, the final cover type for each WMU can be divided into the following three categories:

1. **Fully Covered:** Includes landfills in which all of the WMUs at a landfill are entirely covered with a final cover.
2. **Partially Covered:** Includes landfills where at least one WMU (or portion thereof) is covered with a final cover and another WMU (or portion thereof) is not covered with a final cover.
3. **Fully Uncovered:** Includes landfills whose WMUs are not covered with a final cover.

The fully uncovered category had the largest number of sites with approximately 65 percent of the 224 landfills (146 landfills). Note that the 146 landfills include many sites that are currently operating and are not required to construct a final cover until the time of closure. Figure 2.15 presents the distribution of final cover status for all 224 landfills. At the time of the study, 66 of the 224 landfills in this study were not accepting waste. Of these 66 landfills, 24 (36 percent) were also not fully covered. Generally, these sites were in the process of closure or awaiting regulatory approval for the construction of a cover.

Figure 2.15: Distribution of Final Cover Types

Final Cover Type	Number of Landfills	Percent of Total
Fully Covered	48	21.4
Partially Covered	30	13.4
Fully Uncovered	146	65.2
Total	**224**	**100**

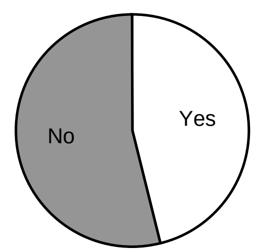


2.2.11 Landfill Gas Collection System

Federal regulations (40 CFR Part 60, Subpart WWW: Standards of Performance for New Stationary Sources and 40 CFR Part 60, Subpart Cc: Emission Guidelines for Control of Existing Sources) require that when an operating landfill is larger than 2.5 million cubic meters or 2.5 million grams in capacity or when the landfill has non-methane organic compound emissions in excess of 50 million grams per year, the discharger must install a system to extract and control the gases generated at the landfill. In other cases, a landfill gas collection system may be required as part of a corrective action program, and/or EA enforcement action. Of the 224 sites in the study, 103, or 46 percent, have engineered systems in place to collect landfill gas and 121 sites, or 54 percent, do not. This distribution is shown in Figure 2.16.

Figure 2.16: Distribution of Gas Collection Systems

Gas Collection System	Number of Landfills	Percent of Total
Yes	103	46.0
No	121	54.0
Total	**224**	**100**



2.2.12 Site Status

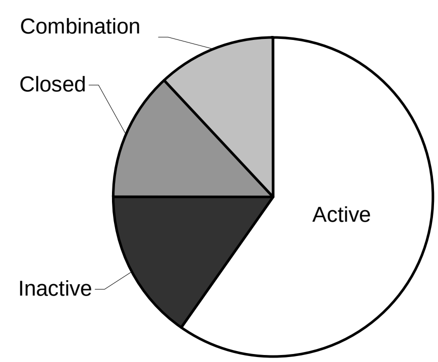
The site status is the operational state of the MSW landfill during the time of the study—from January 1, 1998, to December 31, 2001. For this study, the following four categories were used:

1. **Active:** The landfill was accepting solid waste for disposal during the time of the study.
2. **Inactive:** The landfill was not accepting solid waste for disposal during the time of the study and had not completed closure in accordance with applicable statutes, regulations, and local ordinances in effect during the time of the study.
3. **Closed:** The landfill had ceased accepting solid waste for disposal and had documented that closure was conducted in accordance with applicable statutes, regulations, and local ordinances in effect at the time of the study.
4. **Combination:** The landfill consisted of more than one waste management unit in different operational states at the time of the study (for example, one closed unit and one active unit).

The active category had the largest number of sites, 128, with approximately 57.2 percent of the total. With the addition of the 30 that are partially active (a subset of the 31 in the "Combination" category), the total number of sites with at least one waste management unit active is 158, or 71 percent of the total sites evaluated. Figure 2.17 presents the distribution of site status.

Figure 2.17: Distribution of Site Status

Site Status	Number of Landfills	Percent of Total
Active	128	57.2
Inactive	34	15.2
Closed	31	13.8
Combination	31	13.8
Total	**224**	**100**



2.2.13 Fill Method

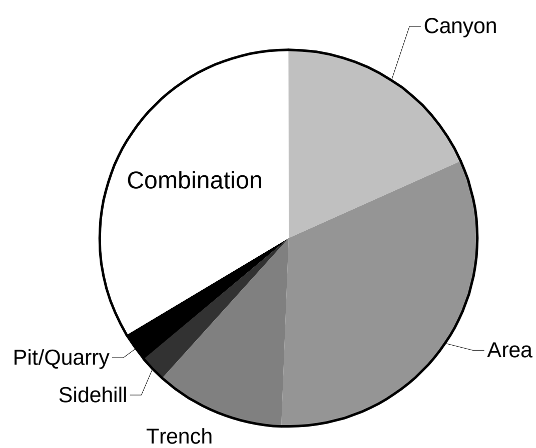
During placement of waste, different sites may use different filling methods. Additionally, any single site may have used more than one method throughout its history. Six fill methods were identified, and all landfills were classified into at least one of the methods. These fill methods and their descriptions are as follows:

1. **Canyon Fill:** Disposing of solid waste by filling in a canyon.
2. **Area Fill:** Disposing of solid waste by filling across a flat area.
3. **Trench Fill:** Disposing of solid waste by filling an excavated trench.
4. **Side-Hill Fill:** Disposing of solid waste by filling across a sloped area.
5. **Pit/Quarry Fill:** Disposing of solid waste by filling an existing pit or quarry that was excavated for a purpose other than waste disposal, such as a mining operation.
6. **Combination:** Disposing of solid waste by using more than one of the above methods.

Combination sites were the most common method, with 75 sites, or 33.5 percent of the total. Figure 2.18 shows the distribution fill method.

Figure 2.18 Distribution of Fill Methods

Fill Method	Number of Landfills	Percent of Total
Canyon Fill	41	18.3
Area Fill	72	32.1
Trench Fill	25	11.2
Side-Hill Fill	5	2.2
Pit/Quarry Fill	6	2.7
Combination	75	33.5
Total	**224**	**100**



3 Methodology for Environmental Performance Screening Analyses

3.1 Introduction

Separate analyses were conducted to evaluate the relationships between landfill site characteristics and environmental performance for the data contained in the database. This section describes the selection and classification of the data and the statistical methods used to evaluate possible relationships.

3.2 Statistical Analysis Approach

For the purposes of the statistical analyses described in this section, the terms “independent” and “dependent” are used frequently to describe the assumed relationship between landfill site characteristics and environmental responses. In most analyses conducted in this study, the assumed independent variable represents a landfill site characteristic, such as owner type or average annual precipitation. The assumed dependent variable is a measure of environmental performance, such as “In Corrective Action,” typically described by a regulatory action. The terms “independent” and “dependent” refer to the relationship between the two variable types. It is assumed that the independent variable by itself results in certain dependent variable conditions, impacting the status or nature of these conditions. Therefore, the former variable is the “causative” one, and the latter is the “response” variable.

Analyses were conducted to explore whether the available data indicate any statistically significant relationships between independent site variables and the dependent environmental response variables. Logistic regression analyses were used for the categorical variables. For the continuous variables, non-parametric analysis of variance using the two-sample Kruskal-Wallis test (also known as the Mann-Whitney test) was used. A detailed description of the statistical methods is presented in Appendix B-1.

3.2.1 Assumed Independent Variables

For these analyses, the landfill site characteristics (such as owner type) contained in the Task 2 database were assumed to be the independent variables. Each independent variable either has at least two mutually exclusive values and/or a “continuous” value (steady stream of data). These landfill site characteristics that were evaluated and their possible values include:

1. *Owner Type* (public or private). Note that public landfills include all federal, State, county, district, tribe, and city landfills. Mutually exclusive variable.
2. *Landfill Age.* Analyses were performed using a continuous value (age 0–100 years) or mutually exclusive values (such as [1] construction during/before or after 1984 or [2] age in 20-year increments or ages outside the increments). Continuous or mutually exclusive variable.
3. *Landfill Size (Permitted Disposal Area)*. Continuous variable.
4. *Social Setting* (rural or non-rural). Note that non-rural settings include both urban and suburban landfills. Mutually exclusive variable.
5. *Physical Setting* (desert, coastal, alpine, high desert, estuarine, or inland). Mutually exclusive variable.
6. *Underlying Geologic Material* (sand and/or gravel, silts/clays, sedimentary rock, or igneous rock). Mutually exclusive variable.

7. *Minimum Depth to Underlying Groundwater.* Continuous variable.
8. *Average Annual Precipitation.* Continuous variable.
9. *Liner Type (Whole Site)* (fully Subtitle D or Subtitle D engineered alternative, fully lined and partially non-Subtitle D, partially unlined, or fully unlined). Mutually exclusive variable.
10. *Final Cover Type (Whole Site)* (fully covered, partially uncovered, or fully uncovered). Mutually exclusive variable.
11. *Landfill Gas Collection System* (Yes or No). Mutually exclusive variable.

3.2.2 Assumed Dependent (Environmental Response) Variables

The dependent variables are those that serve as indicators of environmental performance and can be dependent on the independent variables described above. As described in greater detail in Section 3.3 below, these are:

1. "In Corrective Action."
2. "Has Gas Inspection Report."
3. "Has Gas Enforcement Action."
4. "Has Surface Water Action."
5. "Has Air Quality Violation."

3.3 Indicators of Environmental Performance

3.3.1 Approach and Assumptions

Typically, environmental performance for a landfill can be assessed based on the measured properties of the groundwater, leachate, air, soil, and surface water relative to some standard. The standard may be the background levels, historical values, or regulatory limits. Measurements for any given site, when observed over time, can be compared against a standard to evaluate the site's performance.

Because each site in this study has a unique physical and operating environment, examining the performance of all 224 sites with respect to each other represents an extremely complex analysis. Monitoring frequency, monitoring point location, background characteristics, historic measurements, constituents of concern, and reporting formats can vary greatly from site to site. Additionally, the amount of data required to make such an assessment is well beyond the scope of this work. Recognizing that quantifying environmental performance is a complex and difficult for any given site, much less 224 sites at once, an alternative measure of environmental performance was required.

For these analyses, the actions taken by the various regulators were used as an indicator of environmental performance. One duty that is entrusted to each regulator is to take action if certain environmental standards are not being met. Three principal assumptions must be made in order to use these types of regulatory actions as reliable indicators of environmental performance. The assumptions are as follows:

1. The monitoring systems at each site (such as groundwater wells and gas probes) are located, monitored, and reported in such a way that the site regulators have an adequate picture of the actual environmental performance.

2. The actions the regulators take are appropriate responses for actual environmental impacts. The assumption requires that when presented with the site-specific data, the regulator draws an appropriate conclusion and takes an appropriate action. For example, if there is strong groundwater monitoring evidence that a landfill is impacting the underlying groundwater, then it is assumed that the RWQCB would issue a cleanup and abatement order or would require a corrective action program.

3. The actions that regulators take are relatively uniform across the state. For example, if leachate seeps are observed by one EA in northern California and a leachate control violation is issued, then an EA in southern California observing identical seeps would also issue an identical leachate control violation.

For this screening-level analysis, these three assumptions are reasonable.

3.3.2 Sources for Indicators of Environmental Performance (Dependent Variables)

Because this study was designed as a cross-media study of landfill performance, the indicators of environmental performance were selected from the database with respect to the site's groundwater, surface water, and air. The selected variables are "In Corrective Action," "Has Gas Inspection Report," "Has Gas Enforcement Action," "Has Surface Water Action," and "Has Air Quality Violation." Table 3-A shows the regulatory agencies responsible for oversight of each of the environmental performance indicators.

Table 3-A: Regulatory Agencies That Oversee Environmental Performance Indicators

Regulatory Agency Overseeing Environmental Performance		Environmental Performance Indicator (Dependent Variable)
State Oversight	**Local Oversight**	
State Water Resources Control Board	Regional Water Quality Control Board	"In Corrective Action"
California Integrated Waste Management Board	Enforcement Agency	"Has Gas Inspection Report"
		"Has Gas Enforcement Action"
		"Has Surface Water Action".
California Air Resources Board	Air Districts	"Air Quality Violation"

RWQCB Information (Water-Related Environmental Performance)

Monitoring status categories used by RWQCBs were chosen as the principal indicators for water-related environmental performance. This variable characterizes the state of groundwater, surface water, and unsaturated zone monitoring at an MSW landfill during the time of the study. Landfills are required to establish a monitoring program to detect at the earliest possible time a release from the landfill that could threaten water quality and to report this information to the RWQCB. The following four monitoring programs are required by State regulations:

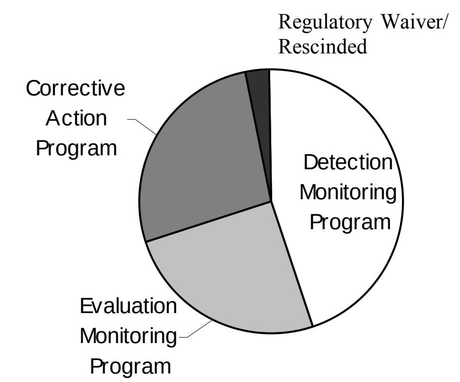
1. **Detection Monitoring:** This is the general default monitoring program. The program initiated at the landfill must at a minimum comply with section 20420 of Title 27 of the CCR. Generally, at this level of monitoring, samples are collected to detect possible releases.

2. **Evaluation Monitoring**: This type of program is required to be instituted whenever there is "measurably significant" evidence of a release from the landfill during a detection monitoring program. An evaluation monitoring program initiated at a landfill must at a minimum comply with section 20425 of Title 27 of the CCR. At this level of monitoring, the nature and extent of the release from the landfill is assessed and a corrective action program is designed, if appropriate.
3. **Corrective Action:** This type of monitoring program is required to be instituted whenever the RWQCB determines that the nature and extent of a release (as determined from evaluation monitoring), and warrants corrective action. The corrective action program initiated at the landfill must at a minimum comply with section 20430 of Title 27 of the CCR. At this level, action is taken to remediate releases from the landfill to achieved compliance with the appropriate water quality standard.
4. **Regulatory Waiver** or **Rescinded:** This status indicates the landfill has a waiver from the monitoring requirements by the RWQCB, typically because the monitoring would be impractical or groundwater is at great depths beneath the landfill. Landfill monitoring requirements can be rescinded by the RWQCB when, in its judgment, the landfill no longer poses a potential threat to the waters of the state.

Looking at the distribution of this variable across the population of 224 landfills, Detection Monitoring had the largest number of sites, with approximately 45 percent (100 landfills) of the total. Figure 3.1 presents the distribution of RWQCB monitoring status for all 224 landfills.

Figure 3.1: Distribution of RWQCB Monitoring Status

Monitoring Status	Number of Landfills	Percentage of Total
Detection Monitoring Program	100	44.6
Evaluation Monitoring Program	56	25.0
Corrective Action Program	61	27.2
Regulatory Waiver or Rescinded	7	3.1
Total	**224**	**100**



Of the four, the corrective action program status is the most indicative of a known environmental impact. In addition to requiring a corrective action, an RWQCB may issue a cleanup and abatement order that requires action on the part of the landfill owner/operator to mitigate a problem. Because some RWQCBs are more likely to issue cleanup and abatement orders than to require corrective action programs, water-related cleanup and abatement orders were also used as an indicator of a site's environmental performance.

Combining these two regulatory actions, the Boolean variable "In Corrective Action" was established. The two possible values of this variable are shown in Table 3-B.

Table 3-B: Possible Values of the "In Corrective Action" Variable

Value	Meaning
Yes	Landfill is either required to conduct a corrective action program <u>or</u> is under a water-related cleanup and abatement order.
No	Landfill is not required to conduct a corrective action program <u>and</u> is not under a water-related cleanup and abatement order.

EA Information (Gas-Related and Surface Water Environmental Performance)

For most landfills in this study, the EA inspects the site on a monthly basis to observe the site conditions for performance of the regulatory minimum standards. Based on the observations, the EA determines whether the landfill is in compliance with or in violation of each standard. Additionally, the EA may find that something is an "area of concern" (AOC), meaning the conditions may not be fully in compliance but not severe enough to report as a violation. An AOC is not a violation, but indicates a problem that could rise to the level of a violation if not corrected.

For this assessment, standards from the following gas-related sections in 27 CCR were used:

- 20919 **Gas Control:** Requires the owner of a landfill to implement a monitoring program if the EA, local fire control authority, or CIWMB believes a hazard or nuisance may be created by landfill decomposition gases. The program shall not be discontinued until authorized by the requiring agency.
- 20919.5 **Explosive Gasses Control:** Specifies concentration limits for methane gas in on-site structures and at the property boundary, and requires an owner or operator of a landfill to implement a routine methane monitoring program. Specifies the type and frequency of the monitoring. The EA with the concurrence from the CIWMB may establish alternative frequencies for MSW landfills that accept 20 tons or less per day.
- 20921 **Gas Monitoring and Control During Closure and Postclosure:** During the time of closure and postclosure, specifies concentration limits for methane gas and requires an owner or operator of a landfill to implement a routine methane gas monitoring program.
- 21160 **Gas Control/Leachate Contact:** Requires the operator of a landfill to implement and maintain landfill gas control and prevent leachate contact with the public or animals. The owner or operator shall also assure that the leachate collection and removal system designed for the landfill does not interfere with landfill gas control nor promote landfill gas migration.

Combining gas-related inspection results for each standard above, the Boolean variable "Has Gas Inspection Report" was established. The two possible values of this variable are shown in Table 3-C.

Table 3-C: Possible Values of the "Has Gas Inspection Report" Variable

Value	Meaning
Yes	EA reported for the landfill at least one gas-related AOC or violation during the study period of January 1, 1998 through December 31, 2001.
No	EA did not report for the landfill any gas-related AOCs or violations during the study period of January 1, 1998 through December 31, 2001.

With repeated violations of the standards, the EA may issue an enforcement action. A variable was established based on the EA gas-related enforcement actions. For this study, the following types of enforcement actions were used:

- Notices and Orders: There are three types of orders, listed below.

  (1) Corrective Action Order: An order requiring the owner or operator of a facility, disposal site, or operation to take specified action by a specified date to abate a nuisance, or to protect public health and safety or the environment. Typical circumstances under which this order may be issued: Conditions at the facility, disposal site, or operation are creating a nuisance or posing a threat to human health and safety or the environment.

  (2) Cease and Desist Order: An order requiring the owner or operator of a facility, disposal site, or operation to cease and desist any improper action, as specified in PRC section 45005, by a specified date. Typical circumstances under which this order may be issued: Facility, disposal site or operation is in violation of Division 30 of the Public Resources Code, any regulations adopted pursuant to Division 30, or causes or threatens to cause a condition of hazard, pollution, or nuisance.

  (3) Compliance Order: Upon any of the grounds specified in PRC section 45011(a)(1), an order establishing a time schedule according to which the owner or operator of the facility, disposal site, or operation shall correct any violations and/or abate a potential or actual threat to public health and safety or the environment. Typical circumstances under which this order may be issued: Facility, disposal site, or operation is in violation of Division 30 of the Public Resources Code, any regulations adopted pursuant to Division 30, any corrective action or cease or desist order, or poses a potential threat to public health and safety or the environment. A compliance order must be issued pursuant to PRC section 45011 as a prelude to the assessment of administrative civil penalties.

- Stipulated Notice and Order: A notice and order to which the EA and owner or operator of the facility, disposal site, or operation have agreed to the terms and conditions of the notice and order.

- Listed on CIWMB's "Inventory of Solid Waste Facilities Violating State Minimum Standards." (www.ciwmb.ca.gov/LEACentral/Inventory/). The inventory is a list of solid waste facilities in California that are violating the State Minimum Standards for solid waste handling and disposal. Three steps must be taken as part of due process in placing a facility on the inventory:

Step One: An EA documents, in two consecutive monthly inspection reports, violations of one or more standards identified as "state minimum standards" for solid waste handling and disposal in Title 14 or Title 27, California Code of Regulations (14 CCR or 27 CCR).

Step Two: When CIWMB staff note at least one violation for two consecutive months, a letter is sent to the operator of the facility notifying the operator of the CIWMB's intent to place the facility in the inventory if the violations are not corrected within 90 days of receipt of the notice. Such a letter is referred to as a "notice of intent" or NOI.

Step Three: On or after the 90th day subsequent to the operator's receipt of the NOI, if one or more of the violations noticed have not been corrected as documented in an inspection report submitted by the EA, CIWMB staff will send another letter to the operator, telling the operator that the facility has been placed on the inventory. A letter telling an operator that a facility is on the inventory is referred to as an "inclusion letter." Board staff may consult with the EA verbally before sending out either an NOI or an inclusion letter to confirm that each is based on accurate and up-to-date information.

Combining these gas-related enforcement actions, a Boolean variable, "Gas Enforcement Action," was established. The two possible values of this variable are shown in Table 3-D.

Table 3-D: Possible Values of the "Has Gas Enforcement Action" Variable

Value	Meaning
Yes	EA issued the landfill at least one gas-related enforcement action during the study period of January 1, 1998 through December 31, 2001.
No	EA did not issue the landfill any gas-related enforcement actions during the study period of January 1, 1998 through December 31, 2001.

In addition to the gas-related standards, a surface-water indicator was selected from the EA information. All EA- reported AOCs and violations for leachate control (27 CCR section §20790) were combined with all EA-reported AOCs and violations for drainage and erosion control (27 CCR section §20820) for the Boolean variable termed "Surface Water Action."

- 20790 Leachate Control: Operator shall ensure that leachate is controlled to prevent contact with the public.
- 20820 Drainage and Erosion Control: Drainage system shall be designed and maintained to ensure integrity of roads, structures, and gas monitoring and control systems; prevent safety hazards; and prevent exposure of waste.

The two possible values of this variable are shown in Table 3-E.

Table 3-E: Possible Values of the "Has Surface Water Action" Variable

Value	Meaning
Yes	EA reported for the landfill at least one leachate control AOC or violation or at least one drainage and erosion control enforcement action during the study period of January 1, 1998 through December 31, 2001.
No	EA did not report for the landfill any leachate control AOC or violations or drainage and erosion control enforcement action during the study period of January 1, 1998 through December 31, 2001.

AQMD/APCD Information (Air Quality Environmental Performance)

The final indicator of environmental performance was chosen from the information provided by AQMDs and APCDs. There are 35 air districts in California. Each district has established its own set of rules pertaining to landfills. These rules may vary slightly due to the areas they are in being classified as attainment or non-attainment zones for ozone. The majority of these rules were adopted to implement the federal requirements for "new" and "existing" larger MSW landfills. Some district landfill rules also apply to smaller landfills in an effort to obtain further VOC emission reductions.

The information on air quality environmental performance is from the following two AQMDs:

- South Coast Air Quality Management District (SCAQMD).
- Bay Area Air Quality Managements District (BAAQMD).

These two districts were chosen based on their large number of landfills and on the amount of information that was provided by each district for the Task 2 database.

Notices to comply and notices of violations issued by these two AQMDs were combined as an indicator of environmental performance and a Boolean variable was established termed "Air Quality Violation." The two possible values of this variable are shown in Table 3F.

Table 3F: Possible Values of the "Has Air Quality Violation" Variable

Value	Meaning
Yes	The SCAQMD or the BAAQMD issued the landfill at least one notice to comply or notice of violation during the study period of January 1, 1998 through December 31, 2001.
No	Neither the SCAQMD nor the BAAQMD issued the landfill any notices to comply nor notices of violations during the study period of January 1, 1998 through December 31, 2001.

More detailed discussion of the relationships between the variables and analyses performed to evaluate those relationships is presented in Appendix B. The results of the statistical analyses are summarized in Section 4 and presented in detail in Appendices B-2 through D-1.

3.4 Relationship Between Assumed Independent Variables and Assumed Dependent Variables

In most analyses conducted in this study, the assumed independent variable represents a landfill site characteristic, such as *Annual Precipitation*. The assumed dependent variable is a measure of environmental performance, such as "In Corrective Action," typically described by a regulatory action. It is assumed that the independent variable by itself results in certain dependent variable conditions. The terms "independent" and "dependent" refer to the relationship between the two variable types. The independent variable, by itself, is assumed to impact the status or nature of the dependent variable. Therefore, the former variable is the assumed "causative" variable, and the latter is the assumed "response" variable.

Some landfill site characteristics assumed to be independent, however, are related to other landfill site characteristics, so are not truly "independent." For example, an analysis of the independent variable *Owner Type* and the dependent variable "In Corrective Action" examines the hypothesis that the owner type may influence whether a landfill is in the category "In Corrective Action." The initial statistical analysis result indicated that privately owned landfill sites are more likely than public sites to be in corrective action. However, further analysis showed that *Social Setting* is related to *Owner Type*, as privately owned landfills are more likely that publicly owned landfills to be in non-rural areas. Thus, *Social Setting* may also have a bearing on the corrective action status of landfills. (To view the results for this analysis, including graphical summaries, see Appendix C-1.)

Generally in cases where there is a relationship between the site characteristics, such as this one, the available data and scope of these statistical analyses are insufficient to clearly determine which site variable is most responsible for correlation with the dependent variable.

4 Results of Environmental Performance Analyses by Individual Landfill Site Characteristics

This section presents a summary of environmental performance results by individual landfill site characteristics from various quantitative and statistical analyses (as discussed in Sections 2 and 3). Each landfill site characteristic was evaluated against the following environmental performance variables:

1. In Corrective Action
2. Has Gas Inspection Report
3. Has Gas Enforcement Action†
4. Has Surface Water Action

In addition to these four environmental performance variables, the statistical analyses also evaluated each landfill site characteristic against the "Has Air Quality Violation" environmental performance variable.

As discussed in Section 3.3.2, the environmental performance variable "Has Air Quality Violation" is reported only for the landfills within the SCAQMD and the BAAQMD. Therefore, the statistical analyses for this variable were conducted only on a two-district subset of the full population. The remaining four environmental performance variables were quantitatively evaluated on a statewide basis.

For 11 of the 13 landfill site characteristics, environmental performance results are presented from two levels of analysis of the Task 2 database inventory: (1) a quantitative review presented in this section and (2) a statistical review with results and graphical summaries in Appendices B-2 through C-2. For the two remaining landfill site characteristics (*Site Status* and *Fill Method*), results are presented only for the quantitative review of the Task 2 database.

4.1 Owner Type

Table 4A summarizes environmental performance results for the quantitative review of data in the inventory for the *Owner Type* landfill site characteristic and the four statewide environmental performance variables.

† Any landfill in the "Has Gas Enforcement Action" category is also in the "Has Gas Inspection Report" category due to the fact that the latter variable represents the preliminary step an EA would take before initiating an enforcement action.

Table 4-A: Summary of Environmental Performance Data for *Owner Type*

Owner Type **Categories**	**Number and (Percent) of Landfills in Study**	**Environmental Performance Variables**			
		"In Corrective Action" Number and (percent) of landfills per category	**"Has Gas Inspection Report"** Number and (percent) of landfills per category	**"Has Gas Enforcement Action"** Number and (percent) of landfills per category)	**"Has Surface Water Action"** Number and (percent) of landfills per category
Private	56 (25%)	Yes – 26 (46.4%) No – 30 (53.6%)	Yes – 31 (55.4%) No – 25 (44.6%)	Yes –10 (17.9%) No – 46 (82.1%)	Yes- 16 (28.6%) No – 40 (71.4%)
Public	168 (75%)	Yes – 45 (26.8%) No – 123 (73.2%)	Yes – 81 (48.2%) No – 87 (51.8%)	Yes – 21 (12.5%) No – 147 (87.5%)	Yes – 33 (19.6%) No – 135 (80.4%)

4.1.1 Observations From Quantitative Data Review (Table 4-A)

Privately owned landfills have a higher relative occurrence in each of the four environmental performance variables above than do publicly owned landfills. The significance of this apparent relationship is discussed in the following section.

4.1.2 Findings From Statistical Analysis

A statistical analysis of data pertaining to owner type resulted in the following findings with regard to correlations that could be drawn between the *Owner Type* landfill site characteristic and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"In Corrective Action"

Statistical analysis of data in the inventory shows that private sites are 2.37 times more likely to be in the category "In Corrective Action" than public sites. However, the correlation between private ownership and "In Corrective Action" may to varying degrees be due to the relationship between *Owner Type* and *Social Setting, Landfill Gas Collection System, Liner Type, Landfill Size (Permitted Disposal Area),* or *Average Annual Precipitation*. The latter five variables also exhibited a positive correlation with the category "In Corrective Action" and with *Owner Type*.

To better understand if the variable *Owner Type* is independent in its correlation with corrective action, the potential correlation of *Owner Type* to other independent variables was examined. (For further discussion on the relationship between assumed independent variables and dependent variables, see Section 3.4.) The results for these analyses, including graphical summaries, are provided in Appendix C-1. Based on these further analyses, the following finding can be made: **Owner type is not necessarily an indicator of environmental performance.**

The assumption in the analyses that *Owner Type* is an independent variable assumes that private and public owners are equally likely to own an urban site or a rural site. Further analysis shows that urban sites are more likely to be privately owned and rural sites publicly owned, as described below:

- Private owners are freer to choose sites than public owners. Looking to reduce costs and increase income, private owners are likely to choose sites that provide the most return for the capital investment. These would likely be urban sites, which, because of their size, would generally have greater waste streams than rural sites. On the other hand, public owners may have to provide a suitable disposal site as a public service, regardless of return on investment.
- Urban sites are also more likely to be significantly larger than rural sites and more likely to be partially unlined, increasing the potential for being in the category "In Corrective Action."

No additional statistically significant correlations resulted from the analysis of *Owner* Type with the other four environmental performance variables.

4.2 Landfill Age

Table 4B provides a summary of environmental performance results for the quantitative review of the database for the *Landfill Age* site characteristic and the four statewide environmental performance variables.

Table 4-B: Summary of Environmental Performance Data for *Landfill Age*

***Landfill Age* Categories**	**Number and Percent of Landfills in Study**	**Environmental Performance Variables**			
		"In Corrective Action" Number and (percent) of landfills per category	**"Has Gas Inspection Report"** Number and (percent) of landfills per category	**"Has Gas Enforcement Action"** Number and (percent) of landfills per category	**"Has Surface Water Action"** Number and (percent) of landfills per category
1910s	1 (0.4%)	Yes – 1 (100%) No - 0 (0%)	Yes – 1 (100%) No - 0 (0%)	Yes – 0 (0%) No - 1 (100%)	Yes – 0 (0%) No - 1 (100%)
1920s	3 (1.3%)	Yes – 1 (33%) No - 2 (67%)	Yes – 2 (67%) No - 1 (33%)	Yes – 0 (0%) No - 3 (100%)	Yes – 1 (33%) No - 2 (67%)
1930s	6 (2.7%)	Yes – 3 (50%) No - 3 (50%)	Yes – 5 (83%) No - 1 (17%)	Yes – 2 (33%) No - 4 (67%)	Yes – 1 (17%) No - 5 (83%)
1940s	12 (5.4%)	Yes – 3 (25%) No - 9 (75%)	Yes – 10 (83.3%) No - 2 (16.7%)	Yes – 1 (8.3%) No - 11 (91.7%)	Yes – 1 (8.3%) No - 11 (91.7%)

Landfill Age Categories	Number and Percent of Landfills in Study	Environmental Performance Variables			
		"In Corrective Action" Number and (percent) of landfills per category	**"Has Gas Inspection Report"** Number and (percent) of landfills per category	**"Has Gas Enforcement Action"** Number and (percent) of landfills per category	**"Has Surface Water Action"** Number and (percent) of landfills per category
1950s	32 (14.3%)	Yes – 11 (34,4%) No - 21 (65.6%)	Yes – 19 (59.4%) No – 13 (40.6%)	Yes – 5 (15.6%) No – 27 (84.4)	Yes – 6 (18.8%) No – 26 (81.2%)
1960s	68 (30.4%)	Yes – 27 (39.9%) No - 41 (60.3%)	Yes – 34 (50%) No - 34 (50%)	Yes – 9 (13.2%) No - 59 (86.8%)	Yes – 17 (25%) No - 51 (75%)
1970s	81 (36.2%)	Yes –21 (25.9%) No - 60 (74.1%)	Yes – 36 (44.5%) No - 45 (55.5%)	Yes – 13 (16.0%) No – 68 (84.0%)	Yes – 18 (22.2%) No – 63 (77.8%)
1980s	13 (5.8%)	Yes –1 (7.7%) No - 12 (92.3%)	Yes –3 (23.1%) No - 10 (76.9%)	Yes –1 (7.7%) No - 12 (92.3%)	Yes –2 (15.4%) No - 11 (84.6%)
1990s	8 (3.6%)	Yes –3 (37.5%) No - 5 (62.5%)	Yes –2 (25%) No - 6 (75%)	Yes –0 (0%) No - 8 (100%)	Yes –3 (37.5%) No - 5 (62.5%)

4.2.1 Observations From Quantitative Data Review (Table 4-B)

The following observations were made upon review of Table 4-B:

From the data, it appears that the "Has Gas Enforcement" variable is more common in landfills starting in the 1930s, and 1950s through 1970s than either older or younger landfills.

"In Corrective Action" has the highest relative occurrence in very old landfills (from the 1910s). However, with a sample size of only 1, this quantitative conclusion is likely not significant.

The statistical significance of these apparent relationships is discussed in the following section.

4.2.2 Findings From Statistical Analysis

A statistical analysis of the data pertaining to landfill age resulted in the following findings with regard to correlations that could be drawn between the *Landfill Age* site characteristic and the environmental performance variables. The age categories were grouped in 20-year increments to increase the number of sites in each sample. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"Has Gas Inspection Report"

The age of a site appears to have a strong influence on whether a site is in the category of "Has Gas Inspection Report." The results for three age-based independent variables (21 to 40 years of age, 41 to 60 years of age, and greater than 60 years of age), which can be seen in Appendix B-3, indicate that older sites are more likely to be in the category "Has Gas Inspection Report." In fact, landfills older than 60 years are 4.36 times more likely to be in the category "Has Gas Inspection Report" than other sites. No correlation was found for landfills 20 years of age or less.

No other statistically significant correlations resulted from the analysis of *Landfill Age* with respect to the environmental performance variables.

4.3 Landfill Size *(Permitted Disposal Area)*

Table 4-C, provides a summary of environmental performance results for the quantitative review of the database for the *Landfill Size* site characteristic and four statewide environmental performance variables. As part of this study, data measuring landfill size were gathered for the variables *Permitted Disposal Area, Permitted Disposal Volume, Permitted Maximum Daily Tonnage, and Estimated Remaining Capacity.* Generally, *Permitted Disposal Area, Permitted Disposal Volume, and Maximum Daily Tonnage* are very closely related to each other. Therefore, any single measure can be used to assess correlations with the environmental response variables. For purposes of the study, *Permitted Disposal Area* was selected for analysis. Furthermore, because *Remaining Capacity* conceptually has no physical bearing on the current performance, it was not evaluated.

Table 4-C: Summary of Environmental Performance Data for *Landfill Size (Permitted Disposal Area)*

***Landfill Size (Permitted Disposal Area*) Categories (acres)**	**Number and Percent of Landfills in Study**	**Environmental Performance Variables**			
		"In Corrective Action" Number and (percent) of landfills per category	**"Has Gas Inspection Report"** Number and (percent) of landfills per category	**"Has Gas Enforcement Action"** Number and (percent) of landfills per category	**"Has Surface Water Action"** Number and (percent) of landfills per category
0 – 1.9	6 *(2.7%)*	Yes – 0 (0%) No - 6 *(100%)*	Yes – 0 (0%) No - 6 (100%)	Yes – 0 (0%) No - 6 (100%)	Yes – 0 (0%) No - 6 (100%)
2 – 9.9	22 *(9.8%)*	Yes – 4 (18.2%) No – 18 (81.8%)	Yes – 6 (27.3%) No - 16 (72.7%)	Yes – 2 (9.1%) No - 20 (90.9%)	Yes – 3 (13.6%) No - 19 (86.4%)
10 – 19.9	23 (10.3%)	Yes – 3 (13.0%) No – 20 (87.0%)	Yes – 9 (39.1%) No – 14 (60.9%)	Yes – 2 (8,7%) No – 21 (91.3%)	Yes – 4 (17.4%) No – 19 (82.6%)
20 – 39.9	36 (16.1%)	Yes – 9 (25.0%) No – 27 (75.0%)	Yes – 15 (41.7%) No – 21 (48.3%)	Yes – 2 (5.6%) No – 34 (94.4%)	Yes – 7 (19.4%) No – 29 (80.6%)
40 – 79.9	49 (21.9%)	Yes – 20 (40.8%) No – 29 (59.2%)	Yes – 27 (55.1%) No – 22 (44.9%)	Yes – 10 (20.4%) No – 39 (79.6%)	Yes – 13 (26.5%) No – 36 (73.5%)
80 – 159.9	40 (17.9%)	Yes – 13 (32.5%) No – 27 (67.5%)	Yes – 25 (62.5%) No – 15 (37.5%)	Yes – 6 (15.0%) No – 34 (85.0%)	Yes – 7 (17.5%) No – 33 (82.5%)
160 – 319.9	34 (15.2%)	Yes – 14 (41.2%) No – 20 (58.8%)	Yes – 21 (61.8%) No – 13 (38.2%)	Yes – 5 (14.7%) No – 29 (85.3%)	Yes – 12 (35.3%) No – 22 (64.7%)
320 – 639.9	11 (4.9 %)	Yes – 7 (63.7%)	Yes – 7 (63.7%)	Yes – 3 (27.3%)	Yes – 2 (18.2%)

Landfill Size (Permitted Disposal Area) Categories (acres)	Number and Percent of Landfills in Study	Environmental Performance Variables			
		"In Corrective Action" Number and (percent) of landfills per category	"Has Gas Inspection Report" Number and (percent) of landfills per category	"Has Gas Enforcement Action" Number and (percent) of landfills per category	"Has Surface Water Action" Number and (percent) of landfills per category
		No – 4 (36.3%)	No – 4 (36.3%)	No – 8 (72.7%)	No – 9 (81.8%)
640 or more	3 (1.3%)	Yes – 1 (33.3%) No – 2 (66.7%)	Yes – 2 (66.7%) No – 1 (33.3%)	Yes – 1 (33.3%) No – 2 (66.7%)	Yes – 1 (33.3%) No – 2 (66.7%)

4.3.1 Observations From Quantitative Data Review (Table 4-C)

The data in Table 4-C suggest that landfills that are less than 40 acres in permitted disposal area have a lower occurrence of each environmental performance variable. Small landfills that are less than 2 acres in permitted disposal area appear to have the lowest occurrence of each environmental performance variable.

The statistical significance of these apparent relationships is discussed in the following section.

4.3.2 Findings From Statistical Analysis

A statistical analysis of data pertaining to landfill size resulted in the following findings with regard to correlations that could be drawn between the *Landfill Size* site characteristic (pertaining to permitted disposal area) and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"In Corrective Action"

The permitted disposal area is significantly greater at sites that are "In Corrective Action".

"Has Gas Inspection Report"

The permitted disposal area is significantly greater at sites that are in the category "Has Gas Inspection Report."

"Has Air Quality Violation"

The permitted disposal area is significantly greater at SCAQMD/BAAQMD sites that are in the category "Has Air Quality Violation." However, this finding could be due to the presence of a landfill gas collection system. When the total non-methane organic compound (NMOC) surface emissions exceed 50 million grams per year from the landfill, a landfill gas collection system may be required. Sites with landfill gas collection systems have more potential for air quality violations, since these sites have more equipment that is monitored by air districts, increasing the potential for violations. Therefore, the variables *Landfill Size (Permitted Disposal Area)* and *Landfill Gas Collection System* are not likely independent of each other. For further discussion on the relationship between assumed independent variables and dependent variables, see Section 3.4.

No other statistically significant correlations resulted from the analysis of *Landfill Size (Permitted Disposal Area)* with respect to the other environmental performance variables.

4.4 Social Setting

Table 4-D, provides a summary of environmental performance results for the quantitative review of the database for the *Social Setting* landfill site characteristic and the four statewide environmental performance variables.

Table 4-D: Summary of Environmental Performance Data for *Social Setting*

***Social Setting* Categories**	**Number and Percent of Landfills in Study**	**Environmental Performance Variables**			
		"In Corrective Action" Number and (percent) of landfills per category	**"Has Gas Inspection Report"** Number and (percent) of landfills per category	**"Has Gas Enforcement Action"** Number and (percent) of landfills per category	**"Has Surface Water Action"** Number and (percent) of landfills per category
Urban	71 (31.7%)	Yes – 37 (52.1%) No – 34 (47.9%)	Yes – 49 (69.0%) No – 22 (31.0%)	Yes – 16 (22.5%) No – 55 (77.5%)	Yes – 20 (28.2%) No – 51 (71.8%)
Suburban	14 (6.3%)	Yes – 3 (21.4%) No – 11 (78.6%)	Yes – 6 (42.9%) No – 8 (57.1%)	Yes – 0 (0%) No – 14 (100%)	Yes – 1 (7.1%) No – 13 (92.9%)
Rural	139 (62.1%)	Yes – 31 (22.3%) No – 108 (77.7%)	Yes – 57 (41.0%) No – 82 (59.0%)	Yes – 15 (10.8%) No – 124 (89.2%)	Yes – 28 (20.9%) No – 111 (79.1%)

4.4.1 Observations From Quantitative Data Review (Table 4-D)

Urban landfills have a higher relative occurrence of each of the four environmental performance variables. Suburban landfills have the lowest relative occurrence of gas enforcement actions and surface water actions.

The statistical significance of these apparent relationships is discussed in the following section.

4.4.2 Findings From Statistical Analysis

A statistical analysis of the data pertaining to social setting resulted in the following findings with regard to correlations that could be drawn between the *Social Setting* landfill site characteristic and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"In Corrective Action"

Urban sites are 3.97 times more likely to be in the category "In Corrective Action" than rural sites. No other social settings increase or decrease the likelihood that a site is in corrective action.

"Has Gas Inspection Report"

Urban sites are approximately 3.2 times more likely to be in the category "Has Gas Inspection Report" than rural sites. The Suburban social setting does not increase or decrease the likelihood that a site is in the category "Has Gas Inspection Report."

"Has Gas Enforcement Action"

Urban sites are approximately 2.4 times more likely to be in the category "Has Gas Enforcement Action" than rural sites. None of the suburban sites are in the category "Has Gas Enforcement Action."

No other statistically significant additional correlations resulted from the analysis of *Social Setting* with respect to the other environmental performance variables.

4.5 Physical Setting

Table 4-E provides a summary of environmental performance results for the quantitative review of the database for the *Physical Setting* landfill site characteristic and the four statewide environmental performance variables.

Table 4-E: Summary of Environmental Performance Data for *Physical Setting*

***Physical Setting* Categories**	**Number and Percent of Landfills in Study**	**Environmental Performance Variables**			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
Coastal	17 (7.6%)	Yes – 8 (47.1%) No – 9 (52.9%)	Yes – 10 (58.8%) No – 7 (41.2%)	Yes – 2 (11.8%) No – 15 (88.2%)	Yes – 7 (41.2%) No – 10 (58.8%)
Estuarine	8 (3.6%)	Yes – 2 (25.0%) No – 6 (75.0%)	Yes – 6 (75.0%) No – 2 (25.0%)	Yes – 2 (25.0%) No – 6 (75.0%)	Yes – 3 (37.5%) No – 5 (62,5%)
Desert	58 (25.9%)	Yes – 9 (15.5%) No – 49 (84.5%)	Yes – 21 (36.2%) No – 37 (63.8%)	Yes – 2 (3.4%) No – 56 (96.6%)	Yes – 5 (8.6%) No – 53 (91.4%)
Alpine	13	Yes – 3	Yes – 2	Yes – 2	Yes – 0

Physical Setting Categories	Number and Percent of Landfills in Study	Environmental Performance Variables			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
	(5.8%)	(23.1%) No – 10 (76.9%)	(15.4%) No – 11 (84.6%)	(15.4%) No – 11 (84.6%)	(0%) No – 13 (100%)
High Desert	9 (4.0%)	Yes – 1 (11.1%) No – 8 (88.9%)	Yes – 5 (55.6%) No – 4 (44.4%)	Yes – 0 (0%) No – 9 (100%)	Yes – 0 (0%) No – 9 (100%)
Inland	119 (53.1%)	Yes – 48 (40.3%) No – 71 (59.7%)	Yes – 68 (57.1%) No – 51 (43.9%)	Yes – 23 (19.3%) No – 96 (80.7%)	Yes – 34 (28.6%) No – 85 (71.4%)

4.5.1 Observations From Quantitative Data Review (Table 4E)

Landfills in alpine and high desert settings have a very low occurrence of surface water action. This may be due, in part, to the precipitation accumulating as snowfall rather than rain.

The statistical significance of the data trends are discussed in the following section.

4.5.2 Findings From Statistical Analysis

A statistical analysis of the data pertaining to physical setting resulted in the following findings with regard to correlations that could be drawn between the *Physical Setting* landfill site characteristic and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"In Corrective Action"

Drier sites (those located in desert settings and/or that experience relatively low average annual precipitation) are 3.68 times less likely to be in the category "In Corrective Action" than inland sites. No other physical settings increase or decrease the likelihood that a site is in the category "In Corrective Action."

As noted in Section 2.2.7, desert sites are classified as such in the database based on the amount of precipitation received per year. Therefore, the variable *Physical Setting* is not independent. It is likely that correlations between *Physical Setting* and "In Corrective Action" are related to the category *Average Annual Precipitation*. For further discussion on the relationship between assumed independent variables and dependent variables, see Section 3.4.

"Has Gas Inspection Report"

Desert sites are approximately 2.3 times less likely to be in the category "Has Gas Inspection Report" than inland sites. Alpine sites are approximately 7.3 times less likely than inland sites to be in the category "Has Gas Inspection Report." No other physical settings increase or decrease the likelihood that a site is in the "Has Gas Inspection Report" category.

As stated under "In Corrective Action," correlations between Physical Setting and "In Corrective Action" are likely related to the variable Average Annual Precipitation. However, the correlation between Physical Setting and "Has Gas Inspection Report" may have no relationship to Average Annual Precipitation, as precipitation does not appear to have a significant influence on whether a site is in the category "Has Gas Inspection Report."

"Has Gas Enforcement Action"

Desert sites are approximately 6.7 times less likely to be in the category "Has Gas Enforcement Action," than inland sites. None of the high desert sites were in the category "Has Gas Enforcement Action. No other physical settings increase or decrease the likelihood that a site "Has Gas Enforcement Action."

"Has Surface Water Action"

Desert sites are approximately 4.2 times less likely to be in the "Has Surface Water Action" category than inland sites. Analysis results appear to support the assumption that site status in regard to the category "Has Surface Water Action" is influenced by amount of precipitation.

No other statistically significant correlations resulted from the analysis of *Physical Setting* with respect to the other environmental performance variables.

4.6 Underlying Geologic Material

Table 4-F provides a summary of environmental performance results for the quantitative review of the database for the *Underlying Geologic Material* landfill site characteristic and the four statewide environmental performance variables.

Table 4-F: Summary of Environmental Performance Data for *Underlying Geologic Material*

Underlying Geologic Material **Categories**	**Number and Percent of Landfills in Study**	**Environmental Performance Variables**			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
Silts/Clays	62 (27,7%)	Yes – 18 (29.0%) No – 44 (71.0%)	Yes – 31 (50.0%) No – 31 (50.0%)	Yes – 12 (19.4%) No – 50 (80.6%)	Yes – 20 (32.3%) No – 42 (67.7%)
Sand and/or Gravel	95 (42.4%)	Yes – 35 (36.8%) No – 60 (63.2%)	Yes – 43 (45.3%) No – 52 (54.7%)	Yes – 11 (11.6%) No – 84 (88.4%)	Yes – 13 (13.7%) No – 82 (86.3%)
Sedimentary Rock	51 (22.8%)	Yes – 14 (27.5%) No – 37 (72.5%)	Yes – 31 (60.8%) No – 20 (39.2%)	Yes – 8 (15.7%) No – 43 (84.3%)	Yes – 14 (27.5%) No – 37 (72.5%)
Igneous Rock	16 (7.1%)	Yes – 4 (25.0%) No – 12 (75.0%)	Yes – 7 (43.8%) No – 9 (56.2%)	Yes – 0 (0%) No – 16 (100%)	Yes – 2 (12.5%) No – 14 (87.5%)

4.6.1 Observations From Quantitative Data Review (Table 4-F)

Landfills cited over igneous rock have a low occurrence of gas enforcement actions.

4.6.2 Findings From Statistical Analysis

A statistical analysis of the data pertaining to underlying geologic material resulted in the following findings with regard to correlations that could be drawn between the *Underlying Geologic Material* landfill site characteristic and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"Has Gas Inspection Report"

No correlation resulted from the analysis at a 95 percent significance level. However, at a 90 percent significance level, results indicate that a sedimentary rock site is approximately 1.9 times more likely than a sand and/or gravel site to be in the category "Has Gas Inspection Report."

"Has Gas Enforcement Action"

None of the igneous rock sites were in the category "Has Gas Enforcement Action." No other underlying geologic materials increase or decrease the likelihood that a site is in the category "Has Gas Enforcement Action."

"Has Surface Water Action"

Sites constructed on sedimentary rock are 2.4 times more likely to be in the category "Has Surface Water Action" than sand and/or gravel sites. Sites constructed on silts/clays are 3.0 times more likely to be in the category "Has Surface Water Action" than sand and/or gravel sites.

No other statistically significant correlations resulted from the analysis of *Underlying Geologic Material* with respect to the other environmental performance variables.

4.7 Minimum Depth to Underlying Groundwater

Table 4-G provides a summary of environmental performance results for the quantitative review of the database for the *Minimum Depth to Underlying Groundwater* landfill site characteristic and the four statewide environmental performance variables.

Table 4-G: Summary of Environmental Performance Data for *Minimum Depth to Underlying Groundwater*

***Minimum Depth to Underlying Groundwater* Categories (feet)**	**Number and Percent of Landfills in Study**	**Environmental Performance Variables**			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
0 – 4.9	37 (16.5%)	Yes –13 (35.1%) No – 24 (64.9%)	Yes –19 (51.4%) No – 18 (48.6%)	Yes –2 (5.4%) No – 35 (94.6%)	Yes –12 (32.4%) No – 25 (67.6%)
5 – 9.9	21 (9.4%)	Yes –8 (38.1%) No – 13 (61.9%)	Yes –10 (47.6%) No – 11 (52.4%)	Yes – 6 (28.6%) No – 15 (71.4%)	Yes –4 (19.0%) No – 17 (81.0%)
10 – 49	62 (27.7%)	Yes –24 (38.7%) No – 38 (61.3%)	Yes –30 (48.4%) No – 32 (51.6%)	Yes –10 (16.1%) No – 52 (83.9%)	Yes –18 (29.0%) No – 44 (71.0%)
50 – 99	42 (18.8%)	Yes –12 (28.6%)	Yes –28 (66.7%)	Yes –5 (11.9%)	Yes –6 (14.3%)

***Minimum Depth to Underlying Groundwater* Categories (feet)**	**Number and Percent of Landfills in Study**	**Environmental Performance Variables**			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
		No – 30 (71.4%)	No – 14 (33.3%)	No – 37 (88.1%)	No – 36 (85.7%)
100 – 199	30 (13.4%)	Yes – 6 (20.0%) No – 24 (80.0%)	Yes –12 (40.0%) No – 18 (60.0%)	Yes –5 (16.7%) No – 25 (83.3%)	Yes –5 (16.7%) No – 25 (83.3%)
200 – 499	23 (10.3%)	Yes –5 (21.7%) No – 18 (78.2%)	Yes –9 (39.1%) No – 14 (60.9%)	Yes –2 (8.7%) No – 21 (91.3%)	Yes –1 (4.3%) No – 22 (95.7%)
500 or more	9 (4.0%)	Yes –3 (33.3%) No – 6 (66.7%)	Yes – 4 (44.4%) No – 5 (55.6%)	Yes –1 (11.1%) No – 8 (88.9%)	Yes –3 (33.3%) No – 6 (66.7%)

4.7.1 Observations From Quantitative Data Review (Table 4-G)

The data presented above quantitatively do not appear to suggest any trends between the two variables.

4.7.2 Findings From Statistical Analysis

A statistical analysis of the data pertaining to minimum depth to underlying groundwater in Table 4G resulted in the following findings with regard to correlations that could be drawn between the *Minimum Depth to Underlying Groundwater* site characteristic and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"Has Surface Water Action"

The minimum depth to underlying groundwater is significantly less at those sites in the category "Has Surface Water Action." In addition to higher groundwater levels, an analysis of sites in the category "Has Surface Water Action" also shows these sites to have significantly greater precipitation.

No other statistically significant correlations resulted from the analysis of *Minimum Depth to Underlying Groundwater* with respect to the other environmental performance variables.

4.8 *Average Annual Precipitation*

Table 4-H provides a summary of environmental performance results for the quantitative review of the database for the *Average Annual Precipitation* landfill site characteristic and the four statewide environmental performance variables.

Table 4-H: Summary of Environmental Performance Data for *Average Annual Precipitation*

Average Annual Precipitation Categories (inches)	Number and Percent of Landfills in Study	Environmental Performance Variables			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
0 – 9.9	71 (31.7%)	Yes –14 (19.7%) No – 57 (80.3%)	Yes –26 (36.6%) No – 45 (63.4%)	Yes –2 (2.8%) No – 69 (97.2%)	Yes – 4 (5.6%) No – 67 (94.4%)
10 – 19.9	96 (42.9%)	Yes –37 (38.5%) No – 59 (61.5%)	Yes –59 (61.5%) No – 37 (38.5%)	Yes – 23 (24.0%) No – 73 (76.0%)	Yes –28 (29.2%) No – 68 (70.8%)
20 – 29.9	30 (13.4%)	Yes –13 (43.3%) No – 17 (56.7%)	Yes –21 (70.0%) No – 9 (30,0%)	Yes –6 (25.0%) No – 24 (75.0%)	Yes –13 (43.3%) No – 17 (56.7%)
30 – 39.9	15 (6.7%)	Yes –5 (33.3%) No – 10 (66.7%)	Yes –3 (20.0%) No – 12 (80.0%)	Yes –0 (0.0%) No – 15 (100%)	Yes –5 (33.3%) No – 10 (66.7%)
40 – 49.9	3 (1.3%)	Yes –1 (33.3%) No – 2 (66.7%)	Yes –1 (33.3%) No – 2 (66.7%)	Yes –0 (0.0%) No – 3 (100.0%)	Yes –2 (66.7%) No – 1 (33.7%)
50 – 59.9	6 (2.7%)	Yes – 0 (0.0%) No – 6 (100.0%)	Yes –1 (16.7%) No – 5 (83.3%)	Yes –0 (0.0%) No – 6 (100.0%)	Yes –2 (33.3%) No – 4 (66.7%)
60 – 69.9	2 (0.9%)	Yes –0 (0.0%) No – 2 (100.0%)	Yes –0 (0.0%) No – 2 (100.0%)	Yes –0 (0.0%) No – 2 (100.0%)	Yes –1 (50.0%) No – 1 (50.0%)

Average Annual Precipitation Categories (inches)	Number and Percent of Landfills in Study	Environmental Performance Variables			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
70 – 79.9	1 (0.4%)	Yes –1 (100.0%) No – 0 (0.0%)	Yes –1 (100.0%) No – 0 (0.0%)	Yes –0 (0.0%) No – 1 (100%)	Yes –1 (100.0%) No – 0 (0.0%)

4.8.1 Observations From Quantitative Data Review (Table 4-H)

Gas inspection reports are more concentrated in sites with average annual precipitation of less than 30 inches. Gas enforcement actions are more concentrated in sites with average annual precipitation ranging from 10 inches to 30 inches.

The statistical significance of these apparent relationships and others is discussed in the following section.

4.8.2 Findings From Statistical Analysis

A statistical analysis of the data pertaining to average annual precipitation resulted in the following findings with regard to correlations that could be drawn between the *Average Annual Precipitation* site characteristic and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"In Corrective Action"

Annual precipitation depths are significantly greater at sites that are in the category "In Corrective Action." Drier sites (those located in desert settings and/or that experience relatively low annual precipitation) are less likely to exhibit groundwater-related environmental indicators than wetter sites.

"Has Surface Water Action"

Average annual precipitation amounts are significantly greater at sites that are in the category "Has Surface Water Action." Analysis results appear to support the assumption that whether a site is in the category "Has Surface Water Action" is influenced by the amount of precipitation. The data appears to support the conclusion that sites that have significantly greater precipitation are more likely to be both in the "In Corrective Action" and the "Has Surface Water Action" categories.

No other additional statistically significant correlations resulted from the analysis of *Average Annual Precipitation* with respect to the other environmental performance variables.

4.9 Liner Type

Table 4-I, below, provides a summary of environmental performance results for the quantitative review of the database for the *Liner Type* landfill site characteristic and the four statewide environmental performance variables.

Table 4-I: Summary of Environmental Performance Data for Landfill *Liner Type*

Liner Type Categories	Number and (Percent) of Landfills in Study	Environmental Performance Variables			
		"In Corrective Action" Number and percent of landfills per category	**"Has Gas Inspection Report"** Number and percent of landfills per category	**"Has Gas Enforcement Action"** Number and percent of landfills per category	**"Has Surface Water Action"** Number and percent of landfills per category
Fully Subtitle D	4 (1.8%)	Yes – 1 (25.0%) No – 3 (75.0%)	Yes – 2 (50.0%) No – 2 (50.0%)	Yes – 0 (0.0%) No – 4 (100.0%)	Yes – 1 (25.0%) No – 3 (75.0%)
Fully Lined, Partially Non-Subtitle D	12 (5.4%)	Yes – 5 (41.7%) No – 7 (58.3%)	Yes – 7 (58.3%) No – 5 (41.7%)	Yes – 3 (25.0%) No – 9 (75.0%)	Yes – 2 (16.7%) No – 10 (83.4%)
Partially Unlined	70 (31.3%)	Yes – 32 (45.7%) No – 38 (54.3%)	Yes – 47 (67.1%) No – 23 (32.9%)	Yes – 15 (21.4%) No – 55 (78,6%)	Yes – 18 (25.7%) No – 52 (74.3%)
Fully Unlined	138 (61.6%)	Yes – 33 (23.9%) No – 105 (76.1%)	Yes – 56 (40.6%) No – 82 (59.4%)	Yes – 13 (9.4%) No – 125 (90.6%)	Yes – 28 (20.3% No – 110 (79.7%)

4.9.1 Observations From Quantitative Data Review (Table 4-I)

Fully Subtitle-D lined sites and fully unlined sites have approximately the same relative occurrence of "In Corrective Action." Partially unlined landfills have the highest occurrence in the categories "In Corrective Action" and "Gas Inspection Report."

The statistical significance of these apparent relationships is discussed in the following section.

4.9.2 Findings From Statistical Analysis

A statistical analysis of the Liner Type data resulted in the following findings with regard to correlations that could be drawn between the *Liner Type* landfill site characteristic and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"In Corrective Action"

Partially unlined sites are 2.75 times more likely to be in the category "In Corrective Action" than sites that are fully unlined. No other liner category increases or decreases the likelihood that a site is in the category "In Corrective Action" relative to fully unlined sites.

Further analysis of partially unlined sites indicates that one possible reason why these sites are more likely than fully unlined sites to be in the category "In Corrective Action" is that they tend to be significantly larger. This suggests that the *Liner Type* variable may not be independent of the *Landfill Size (Permitted Disposal Area)* variable. For further discussion on the relationship between assumed independent variables and dependent variables, see Section 3.4.

An analysis of possible dependence between *Liner Type* and *Landfill Size (Permitted Disposal Area)* was conducted, looking specifically at the difference between partially unlined and fully unlined sites. The results, summarized in Appendix C-2, provide some support to the hypothesis that landfill size may influence whether certain liner types are more or less likely to be in non-compliance with environmental standards. One suggested explanation for this outcome is that partially unlined sites tend to be large and relatively complex, thereby increasing the likelihood of non-compliance with certain standards.

"Has Gas Inspection Report"

Partially unlined sites are 3.1 times more likely to be in the category "Has Gas Inspection Report" than sites that are fully unlined. No other liner category increases or decreases the likelihood that a site is in the category "Has Gas Inspection Report" relative to fully unlined sites.

As discussed above under "In Corrective Action," it is possible that the *Liner Type* variable is not completely independent of the *Landfill Size* (*Permitted Disposal Area)* variable. Partially unlined sites tend to be relatively large, complex sites, thereby potentially increasing the likelihood that they will be in the category "Has Gas Inspection Report."

"Has Gas Enforcement Action"

Partially unlined sites are 2.7 times more likely to be in the category "Has Gas Enforcement Action" than sites that are fully unlined. No other liner category increases or decreases the likelihood that a site is in the category "Has Gas Inspection Report" relative to fully unlined sites.

As discussed above under "In Corrective Action," partially unlined sites tend to be relatively large, complex sites, thereby potentially increasing the likelihood that they are in the "Has Gas Enforcement Action" category. It is possible that the *Liner Type* variable may not be completely independent of the *Landfill Size (Permitted Disposal Area)* variable.

No other statistically significant correlations resulted from the analysis of *Liner Type* with respect to the other environmental performance variables.

4.10 Final Cover Type

Table 4-J provides a summary of environmental performance results for the quantitative review of the database for the *Final Cover Type* landfill site characteristic and the four statewide environmental performance variables.

Table 4-J: Summary of Environmental Performance Data for *Final Cover Type*

Final Cover Type Categories	Number and Percent of Landfills in Study	Environmental Performance Variables			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
Fully Covered	48 (21.4%))	Yes – 17 (35.4%) No – 31 (64.6%)	Yes – 20 (41.7%) No – 28 (59.3%)	Yes – 1 (2.1%) No – 47 (97.9%)	Yes – 6 (12.5%) No – 42 (87.5%)
Partially Covered	30 (13.4%)	Yes – 13 (43.3%) No – 17 (56.7%)	Yes – 16 (53.3%) No – 14 (46.7%)	Yes – 11 (36.7%) No – 19 (63.3%)	Yes – 10 (33.3%) No – 20 (66.7%)
Fully Uncovered	146 (65.2%)	Yes – 41 (28.0%) No – 105 (72.0%)	Yes – 76 (52.1%) No – 70 (47.9%)	Yes – 19 (13.0%) No – 127 (87.0%)	Yes – 33 (22.6%) No – 113 (77.4%)

4.10.1 Observations From Quantitative Data Review (Table 4-J)

Partially covered landfills have the highest relative occurrence of the each of the four environmental performance variables. Fully covered landfills have the lowest occurrence of the "Has Gas Enforcement" variable.

The statistical significance of these apparent relationships is discussed in the following section.

4.10.2 Findings From Statistical Analysis

A statistical analysis of the data pertaining to final cover type resulted in the following findings with regard to correlations that could be drawn between the *Final Cover Type* landfill site characteristic and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

"Has Gas Enforcement Action"

Partially covered sites are 4.6 times more likely to be in the category "Has Gas Enforcement Action" than fully uncovered sites. No correlation resulted from the analysis of fully covered and fully uncovered sites at a 95 percent significance level. However, at a 90 percent level of significance, results indicate that a fully covered site is approximately 7.3 times less likely that a fully uncovered site to be in the "Has Gas Enforcement Action" category.

As with partially unlined sites, partially uncovered sites tend to be relatively large and complex. This may explain, in part, why the results indicate that partially covered sites are more likely to be in the category "Has Gas Enforcement Action" than fully uncovered sites.

No other statistically significant correlations resulted from the analysis of *Cover Type* with respect to the other environmental performance variables.

4.11 Landfill Gas Collection System

Table 4-K provides a summary of environmental performance results for the quantitative review of the database for the *Landfill Gas Collection System* landfill site characteristic and the four statewide environmental performance variables.

Table 4-K: Summary of Environmental Performance Data for *Landfill Gas Collection System*

Landfill Gas Collection System Categories	Number and Percent of Landfills in Study	Environmental Protection Variables			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
Has System	103 (46.0%)	Yes – 52 (50.5%) No – 51 (49.5%	Yes – 70 (68.0%) No – 33 (32.0%)	Yes – 22 (21.4%) No – 81 (78.5%)	Yes – 25 (24.3%) No – 78 (75.7%)
Does Not Have System	121 (54.0%)	Yes – 19 (15.7%) No – 102 (84.3%)	Yes – 42 (34.7%) No – 79 (65.3%)	Yes – 9 (7.4%) No – 112 (92.6%)	Yes – 24 (19.9%) No – 97 (80.1%)

4.11.1 Observations From Quantitative Data Review (Table 4K)

Landfills with landfill gas collection systems have a higher relative occurrence of each environmental response variables

The statistical significance of these apparent relationships is discussed in the following section.

4.11.2 Findings From Statistical Analysis

A statistical analysis of the data pertaining to landfill gas collections systems resulted in the following findings with regard to correlations that could be drawn between the *Landfill Gas Collection System* landfill site characteristic and the environmental performance variables. The results for this analysis, including graphical summaries, are provided in Appendices B-2 through B-5.

“In Corrective Action”

Sites that have landfill gas collection systems are 5.47 times more likely to be in the category “In Corrective Action” than sites that do not have landfill gas collection systems. This may be due to a variety of reasons:

- The presence of landfill gas collection systems may result in greater regulatory scrutiny, therefore increasing the likelihood that environmental concerns would be identified at a site.
- Landfill gas collection systems may be most prevalent at larger sites and those sites with previous environmental performance concerns. As discussed under the “In Corrective Action,” segment of Section 4.9.2, it is possible that the *Landfill Gas Collection System* variable may not be completely independent of the *Landfill Size (Permitted Disposal Area)* variable.
- The installation of a landfill gas collection system may be the result of corrective action to address other factors. For example, a gas collection system may be required if the total NMOC surface missions exceed 50 million grams per year. In this case, it is the large size of the site (resulting in the total NMOC surface emissions), not the remedy to the situation (installation of a gas collection system) that causes the site to be in the category “In Corrective Action.”

“Has Gas Inspection Report”

Sites that have landfill gas collection systems are 3.1 times more likely to be in the category “Has Gas Inspection Report” than sites that do not have landfill gas collection systems.

As with the “In Corrective Action” category, a site that has a landfill gas collection system is more likely to be in the category “Has Gas Inspection Report” than one that does not have the gas collection system. The reason is because the presence of a landfill gas collection system (necessitated by the site’s greater size and resulting greater gas production) may lead to greater scrutiny by the regulators.

“Has Gas Enforcement Action”

Sites that have landfill gas collection systems are 3.4 times more likely to be in the category “Has Gas Enforcement Action” than sites that do not have landfill gas collection systems. See the discussion under “In Corrective Action” in this section for possible reasons.

“Has Air Quality Violation”

Sites equipped with landfill gas collection systems are 22.1 times more likely to be in the category “Has Air Quality Violation” than sites that do not have landfill gas collection systems.

An evaluation of the category “Has Air Quality Violations” indicates that significantly larger sites with landfill gas collection systems are more likely to be in this category. The reason for this is that sites receiving permits to have landfill gas collection systems have, as a result, equipment that air districts must monitor. More potential therefore exists for violations of the permitted conditions.

Based on the results presented above, the existence of a landfill gas collection system at a landfill is not necessarily an indicator of environmental performance.

The chronology of site history may lead to a more interesting finding—how the installation of a landfill gas collection system has affected environmental performance. Unfortunately, the “snapshot in time” approach to data collection used for the purposes of this report does not lend itself to answering this question.

No additional correlations resulted from the analysis of *Landfill Gas Collection System* with the other environmental performance variables.

4.12 Site Status

Table 4-L provides a summary of environmental performance results for the quantitative review of the database for the *Site Status* landfill site characteristic and the four statewide environmental performance variables.

Table 4-L: Summary of Environmental Performance Data for Site Status

Site Status Categories	Number and Percent of Landfills in Study	Environmental Performance Variables			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
Active	128 (57.2%)	Yes – 32 (25.0%) No – 96 (75.0%)	Yes – 66 (51.6%) No – 62 (48.4%)	Yes – 22 (17.2%) No – 106 (82.8%)	Yes – 29 (22.7%) No – 99 (77.3%)
Inactive	34 (15.2%)	Yes – 11 (32.4%) No – 23 (67.6%)	Yes – 13 (38.2%) No – 21 (61.8%)	Yes – 2 (5.9%) No – 32 (94.1%)	Yes – 8 (23.5%) No – 26 (76.5%)
Closed	31 (13.8%)	Yes – 8 (25.8%) No – 23 (74.2%)	Yes – 11 (35.5%) No – 20 (64.5%)	Yes – 0 (0.0%) No – 31 (100.0%)	Yes – 1 (3.2%) No – 30 (96.8%)
Combination	31 (13.8%)	Yes – 20 (64.5%) No – 11 (35.5%)	Yes – 22 (71.0%) No – 9 (29.0%)	Yes – 7 (22.6%) No – 24 (77.3%)	Yes – 11 (35.5%) No – 20 (64.5%)

4.12.1 Observations From Quantitative Data Review (Table 4-L)

Closed landfills have the lowest relative occurrence of each of the environmental performance variables, with the exception of “In Corrective Action.” Combination sites have the highest relative occurrence of each of the environmental performance variables.

Combination sites, much like the partially covered sites, are more likely to be large and complex and lead to a greater occurrence of the environmental performance variables.

These apparent relationships are more likely a function of cover type than of site status. Closed sites, by definition, must have a final cover. Active sites must be partially uncovered in order to accept new waste. Therefore *Site Status* and *Cover Type* are clearly dependent. Because the *Cover Type* variable was already analyzed statistically, the *Site Status* variable was only evaluated quantitatively.

4.13 Fill Method

Table 4-M provides a summary of environmental performance results for the quantitative review of the database for the *Fill Method* landfill site characteristic and the four statewide environmental performance variables.

Table 4-M: Summary of Environmental Performance Data for *Fill Method*

Fill Method Categories	Number and Percent of Landfills in Study	Environmental Protection Variables			
		In Corrective Action Number and percent of landfills per category	**Has Gas Inspection Report** Number and percent of landfills per category	**Has Gas Enforcement Action** Number and percent of landfills per category	**Has Surface Water Action** Number and percent of landfills per category
Canyon Fill	41 (18.3%)	Yes – 19 (46.3%) No – 22 (53.7%)	Yes – 28 (68.8%) No – 13 (31.2%)	Yes – 5 (12.2%) No – 36 (87.8%)	Yes – 13 (31.7%) No – 28 (68.3%)
Area Fill	72 (32.1%)	Yes – 27 (37.5%) No – 45 (62.5%)	Yes – 40 (55.6%) No – 32 (44.4%)	Yes – 12 (16.7%) No – 60 (83.3%)	Yes – 19 (26.4%) No – 53 (73.6%)
Trench Fill	25 (11.2%)	Yes – 1 (4.0%) No – 24 (96.0%)	Yes – 7 (28.0%) No – 18 (72.0%)	Yes – 0 (0.0%) No – 25 (100.0%)	Yes – 0 (0.0%) No – 25 (100.%)
Side-Hill Fill	5 (2.2%)	Yes – 1 (20.0%) No –4 (80.0%)	Yes – 1 (20.0%) No – 4 (80.0%)	Yes – 0 (0.0%) No – 5 (100.0%)	Yes – 0 (0.0%) No – 5 (100.%)
Pit/Quarry Fill	6 (2.7%)	Yes – 4 (66.7%) No – 2 (33.3%)	Yes – 2 (33.3%) No – 4 (66.7%)	Yes – 1 (16.7%) No – 5 (83.3%)	Yes – 0 (0.0%) No – 6 (100.%)
Combination	75 (33.5%)	Yes – 19 (25.3%) No – 56 (74.7%)	Yes – 34 (45.3%) No – 41 (54.7%)	Yes – 13 (17.3%) No – 62 (82.7%)	Yes – 17 (22.7%) No – 58 (77.3%)

4.13.1 Observations From Quantitative Data Review (Table 4-M)

With the exception of "Has Gas Enforcement Action", landfills with canyon fill methods have the highest relative occurrence of each environmental performance variable. Landfills with either the side hill fill or trench fill methods have the lowest relative occurrence of each environmental performance variable.

5 Results of Multiple-Variable Analyses

Section 5 summarizes the results of multiple-variable analyses of landfill site characteristics to provide the following:

- A profile of a “typical” California MSW landfill.
- A brief overview of the design and operational characteristics of urban, suburban, and rural landfills during the time of the study.
- A review of environmental performance for urban, suburban, and rural landfills by multiple site characteristics.
- A review of environmental performance for active, inactive, closed, and combination landfills by multiple site characteristics.

5.1 *“Typical” California MSW Landfill*

A profile of a “typical” California MSW landfill was derived by looking at the landfill site characteristics described in Section 2.2. To find the typical value for each site characteristic variable, each was statistically evaluated to find the mean, median, or mode.

In the case of a continuous variable with a relatively natural distribution (such as *Average Annual Precipitation*), “typical” was represented by the mean. In the case of a continuous variable with more of a logarithmic distribution (such as *Landfill Size [Permitted Disposal Area]),* “typical” was better represented by the median. In the case of a categorical variable (such as *Owner Type*), “typical” was better represented by the mode.

Based on the results of the statistical evaluation of the database, the typical MSW landfill in California can be described as shown in Table 5-A.

Table 5-A: Profile of a “Typical” California MSW Landfill

Landfill Site Characteristic	Typical Value
Owner Type	Publicly owned (county)
Site Status	Active
Social Setting	Rural
Fill Method	Area or combination
Landfill Size (Permitted Disposal Area)	55.5 acres
Permitted Disposal Volume	2.7 million cubic yards
Permitted Maximum Daily Tonnage	385 tons
Remaining Capacity	2.1 million cubic yards
Physical Setting	Inland
Underlying Geologic Material	Sand and/or gravel
Minimum Depth to Underlying Groundwater	34.5 feet
Average Annual Precipitation	16 inches
Liner Type	Fully unlined or partially unlined (active sites)
Cover Type	Fully uncovered
Landfill Gas Collection System	None

5.1.1 Observations From Data Review (Table 5-A)

The "typical" California MSW landfill is publicly owned, active, located inland, fully unlined or, in the case of active sites, partially unlined, fully uncovered, and has no gas collection system. The typical site is underlain by sand and/or gravel, has a minimum depth to underlying groundwater of 34.5 feet, and receives an average annual precipitation of 16 inches.

While there is no single site within this study that matches each of the above site characteristic values, the four sites that most closely match these typical values are:

- Amador County Landfill/Buena Vista Class II.
- Bass Hill Landfill.
- John Smith Road Class III Landfill.
- Ramona Landfill.

Because these four landfills come closest to representing a typical California MSW landfill, they have been recommended for the Phase II portion of the study, the assessment of regulatory effectiveness. The complete list of 40 landfills recommended for the Phase II portion of the study, including the four listed above, is presented in Section 7.

5.2 Summary and Comparison of Urban, Suburban, and Rural Landfills

5.2.1 Brief Overview of Urban, Suburban, and Rural Landfills by Eight Landfill Site Characteristics

To provide a brief overview of the design and operational characteristics of urban, suburban, and rural landfills during the time of the study, a simplified quantitative data review was completed on the following eight landfill site characteristics:

1. Owner Type
2. Landfill Age
3. Landfill Size (Permitted Disposal Area)
4. Physical Setting
5. Minimum Depth to Underlying Groundwater
6. Average Annual Precipitation
7. Liner Type
8. Landfill Gas Collection System

To streamline the effort, all of the variables used in the quantitative review were reduced to two mutually exclusive values. For example: urban, suburban, and rural landfills were divided into rural and non-rural landfills, with non-rural consisting of both urban and suburban sites; liner types were divided into lined and unlined; and average annual precipitation was divided into less than 14 inches and equal to or greater than 14 inches.

The complete results of this analysis are tabulated in Appendix D-1. From the results, the following statements are made:

1. There are more than twice as many publicly owned rural landfills as publicly owned non-rural landfills.

2. Most of the small landfills (defined here as less than 122 acres) are in rural social settings.
3. Most of the young landfills (defined here as younger than 35 years old) are in rural social settings. Older landfills (defined as 35 years old or greater) are nearly evenly divided between rural and non-rural social settings.
4. Most of the desert sites are in rural settings, whereas the inland sites are nearly evenly divided between rural and non-rural social settings.
5. Most of the landfills with deep groundwater (defined here as greater than or equal to 34.5 feet) are in rural social settings. Landfills with shallow groundwater (defined here as less than 34.5 feet) are nearly evenly divided between rural and non-rural social settings
6. Landfills with relatively low average annual precipitation (less than 14 inches) trend to be rural. Landfills with 14 inches or more of average annual precipitation are nearly evenly divided between rural and non-rural social settings.
7. The majority of fully unlined sites are rural landfills.
8. Most landfills without gas collect systems are in rural social settings.

5.2.2 Summary of Environmental Performance of Urban, Suburban, and Rural Landfills by Five Landfill Site Characteristics

To better understand the environmental performance of urban, suburban, and rural landfills for the time of the study, a quantitative data review was completed on five landfill site characteristics. The quantitative review looked at all of the possible values for each of the site characteristics, unlike the more streamlined approach used in section 5.2.1. In reviewing the results, the reader is provided not only with information on environmental performance at these landfills, but also with a snapshot of the design and operational characteristics of these landfills for the five landfill site characteristics.

The results are summarized and compared against one another for the following five landfill site characteristics:

1. Site Status.
2. Landfill Size (Permitted Disposal Area).
3. Average Annual Precipitation.
4. Liner Type.
5. Landfill Gas Collection System.

Each site characteristic was evaluated against the following environmental performance variables:

1. In Corrective Action.
2. Has Gas Inspection Report.
3. Has Gas Enforcement Action.
4. Has Surface Water Action.

The data was taken from the Task 2 database and covers the time period from January 1998 though December 2001.

5.2.2.1 Results and Observations: Site Status

Table 5-B: Summary of Environmental Performance and Landfill Site Characteristic Data for Urban, Suburban, and Rural Landfills by *Site Status*

Landfill Site Characteristic				Environmental Performance Variables											
***Site Status* Categories**	**Number of Landfills in Study**			**In Corrective Action** Number of landfills per category			**Has Gas Inspection Report** Number of landfills per category			**Has Gas Enforcement Action** Number of landfills per category			**Has Surface Water Action** Number of landfills per category		
	Urban	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**
Active	38	9	81	16	2	14	24	4	38	12	0	10	12	1	16
Inactive	6	3	25	3	1	7	5	1	7	0	0	2	1	0	7
Closed	10	0	21	5	0	3	8	0	3	0	0	0	0	0	1
Combination	17	2	12	13	0	7	12	1	9	4	0	3	7	0	4

Observations From Quantitative Data Review (Table 5-B)

Urban, suburban, and rural landfills show similar relative distributions of active and closed site status. Inactive sites are relatively less common in urban social settings than in either suburban or rural social settings. Combination site status is more common among urban landfills than among either rural or suburban landfills.

Similar to the findings in Section 4.4.2, Table 5B shows that urban landfills have a higher relative occurrence of each environmental performance variable. When subdivided by site status, only the active sites show this same trend.

5.2.2.2 Results and Observations: Landfill Size (Permitted Disposal Area)

Table 5-C: Summary of Environmental Performance and Landfill Site Characteristic Data for Urban, Suburban, and Rural Landfills by *Landfill Size (Permitted Disposal Area)*

Landfill Site Characteristic				Environmental Performance Variables											
Landfill Size (Permitted Disposal Area) **Categories (acres)**	**Number of Landfills in Study**			**In Corrective Action** Number of landfills per category			**Has Gas Inspection Report** Number of landfills per category			**Has Gas Enforcement Action** Number of landfills per category			**Has Surface Water Action** Number of landfills per category		
	Urban	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**
0–9.9	0	0	28	0	0	4	0	0	6	0	0	2	0	0	3
10–99.9	25	8	89	12	2	20	18	4	38	5	0	11	6	1	18
100 or more	46	6	22	25	1	7	31	2	13	11	0	2	14	0	7

Observations From Quantitative Data Review (Table 5-C)

Urban sites are generally larger than rural sites. This is likely a function of the population each landfill serves. Less populated areas require less disposal capacity, whereas densely populated areas require greater disposal capacity. This observation confirms the interdependence of the *Permitted Disposal Area* and *Social Setting* site characteristics as discussed in Section 4.

Small, rural landfills of less than 10 acres in permitted disposal area have relatively low occurrences of each environmental performance variable. Conversely, large, urban landfills have relatively high occurrences of most environmental response variables.

5.2.2.3 Results and Observations: Average Annual Precipitation

Table 5-D: Summary of Environmental Performance and Landfill Site Characteristic Data for Urban, Suburban, and Rural Landfills by *Average Annual Precipitation*

Landfill Site Characteristic				Environmental Performance Variables											
***Average Annual Precipitation* Categories (inches)**	**Number of Landfills in Study**			**In Corrective Action** Number of landfills per category			**Has Gas Inspection Report** Number of landfills per category			**Has Gas Enforcement Action** Number of landfills per category			**Has Surface Water Action** Number of landfills per category		
	Urban	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**
0–8.9	5	7	57	2	2	8	3	2	20	0	0	1	0	0	4
9–24.9	60	7	54	33	1	15	43	4	30	16	0	14	17	1	13
25 or more	6	0	28	2	0	8	3	0	7	0	0	0	3	0	11

Observations From Quantitative Data Review (Table 5-D)

Urban landfills are more highly concentrated in areas with between 9 and 24.9 inches of average annual precipitation, whereas rural sites are more evenly divided among dry, moderate, and wet regions.

Urban landfills with between 9 and 24.9 inches of average annual precipitation have a higher relative occurrence of "In Corrective Action," "Has Gas Inspection Report," and "Has Gas Enforcement Action" than the other combinations of categories. Landfills with 25 inches or more average annual precipitation have the highest relative occurrence of "Has Surface Water Action" in both the urban and rural categories. This observation is similar to the findings presented in Section 4.8.2.

5.2.2.4 Results and Observations: Liner Type

Table 5-E: Summary of Environmental Performance and Landfill Site Characteristic Data for Urban, Suburban, and Rural Landfills by *Liner Type*

Landfill Site Characteristic				Environmental Performance Variables											
***Liner Type* Categories**	**Number of Landfills in Study**			**In Corrective Action** Number of landfills per category			**Has Gas Inspection Report** Number of landfills per category			**Has Gas Enforcement Action** Number of landfills per category			**Has Surface Water Action** Number of landfills per category		
	Urban	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**
Fully Subtitle D	2	0	2	0	0	1	1	0	1	0	0	0	1	0	0
Fully Lined, Partially Non-Subtitle D	7	0	5	4	0	1	5	0	2	3	0	0	2	0	0
Partially Unlined	38	6	26	22	1	9	26	3	18	10	0	5	8	0	10
Fully Unlined	24	8	106	11	2	20	17	3	36	3	0	10	9	1	18

Observations From Quantitative Data Review (Table 5-E)

Fully unlined landfills are more common in rural social settings and partially unlined landfills are more common in urban social settings. This finding is likely a function of the size of the waste streams going to the different sites. Many rural, unlined sites have not reached the capacity of their "pre-regulation" footprint and, therefore, are therefore not required to build lined WMUs at the landfill. Urban landfills, on the other hand, tend to have larger waste streams that need to be accommodated, necessitating the construction of new WMUs at the landfill. The new WMUs were then lined in accordance with the regulations in effect at the time of construction.

The relative distribution of the environmental response variables does not appear to be related to *Social Setting* when divided by *Liner Type*. However, as shown in Section 4.9, partially unlined sites are more likely to have a "yes " value for the categories "In Corrective Action," "Has Gas Inspection Report," and "Has Gas Enforcement Action."

5.2.2.5 Results and Observations: Landfill Gas Collection System

Table 5-F: Summary of Environmental Performance and Landfill Site Characteristic Data for Urban, Suburban, and Rural Landfills by *Landfill Gas Collection System*

Landfill Site Characteristic				Environmental Performance Variables											
***Landfill Gas Collection System* Categories**	**Number of Landfills in Study**			**In Corrective Action** Number of landfills per category			**Has Gas Inspection Report** Number of landfills per category			**Has Gas Enforcement Action** Number of landfills per category			**Has Surface Water Action** Number of landfills per category		
	Urban	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**	**Urban**	**Suburban**	**Rural**
Has System	57	9	37	33	2	17	40	3	27	14	0	8	16	1	8
Does Not Have System	14	5	102	4	1	14	9	2	30	2	0	7	4	0	20

Observations From Quantitative Data Review (Table 5-F)

Landfill gas collection systems are relatively more common at urban and suburban landfills than at rural landfills. With the exception of "Has Gas Inspection Report" at suburban landfills and "Has Surface Water Action" at urban landfills, landfills with gas collection systems have the highest relative occurrence of each environmental performance variable in each social setting.

However, for the reasons stated in section 4.11, the existence of a landfill gas collection system may not be a good indicator of environmental performance.

5.2.2.6 <u>Summary of Observations From Quantitative Data Review For the Five Landfill Site Characteristics</u>

A look at the observations for the five landfill site characteristics leads to the following key observations about urban, suburban, and rural landfills:

- Urban sites are generally larger than rural sites.
- Urban landfills are relatively concentrated in areas with between 9 and 24.9 inches of annual precipitation.
- Rural landfills are distributed broadly over dry, moderate, and wet climates.
- Partially unlined landfills and landfill gas collection systems are more common in urban social settings than in rural social settings.

5.3 Summary of Environmental Performance of Active, Inactive, Closed, and Combination Landfills by Five Landfill Site Characteristics

To better understand the environmental performance of active, inactive, closed, and "combination"‡ landfills for the time of the study, a quantitative data review was completed on five landfill site characteristics. The review of active, inactive, closed, and combination landfills looked at all possible values for each of the site characteristics (instead of two mutually exclusive values, as with the review of urban, suburban, and rural landfills in section 5.2.1). The review provided not only environmental performance information, but also a snapshot of the design and operational characteristics of the landfills in regard to the five site characteristics.

The results are summarized and compared against one another for the following five landfill site characteristics:

1. Landfill Size (Permitted Disposal Area)
2. Minimum Depth to Underlying Groundwater
3. Average Annual Precipitation
4. Liner Type
5. Final Cover Type

Each site characteristic was evaluated against the following environmental performance variables:

1. In Corrective Action
2. Has Gas Inspection Report
3. Has Gas Enforcement Action
4. Has Surface Water Action

The data was taken from the Task 2 database and covers the time period January 1998 though December 2001.

‡ For purposes of this study, a "combination" landfill is one that consists of more than one waste management unit, with the individual units being in different operational states (for example, in a landfill with two units, one unit may be active and the other may be closed).

5.3.1 Results and Observations: Landfill Size (Permitted Disposal Area)

Table 5-G: Summary of Environmental Performance and Landfill Site Characteristic Data for Active, Inactive, Closed, and Combination Landfills by *Landfill Size (Permitted Disposal Area)*

Landfill Site Characteristic					**Environmental Performance Variables**															
***Landfill Size (Permitted Disposal Area)* Categories (acres)**	**Number of Landfills in Study**				**In Corrective Action** Number of landfills per category				**Has Gas Inspection Report** Number of landfills per category				**Has Gas Enforcement Action** Number of landfills per category				**Has Surface Water Action** Number of landfills per category			
	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination
0–9.9	12	7	9	0	2	2	0	0	5	1	0	0	2	0	0	0	0	2	1	0
10–99.9	66	23	16	17	11	7	6	10	31	9	7	13	9	1	0	6	13	6	0	6
100 or more	50	4	6	14	19	2	2	10	30	3	4	9	11	1	0	1	16	0	0	5

Observations From Quantitative Data Review (Table 5-G)

Landfills that have less than 10 acres in permitted disposal area are either active, inactive, or closed, but not a combination of these site statuses.

Closed landfills, regardless of permitted disposal area, have a low relative occurrence of "Has Surface Water Action" and "Has Gas Enforcement Action," whereas combination sites have a high relative occurrence of "Has Surface Water Action" and "Has Gas Enforcement Action." These observations are similar to those found in Section 4.12.1

5.3.2 Results and Observations: Minimum Depth to Underlying Groundwater

Table 5-H: Summary of Environmental Performance and Landfill Site Characteristic Data for Active, Inactive, Closed, and Combination Landfills by *Minimum Depth to Underlying Groundwater*

Landfill Site Characteristic					Environmental Performance Variables															
***Minimum Depth to Underlying Groundwater* Categories (feet)**	**Number of Landfills in Study**				**In Corrective Action** Number of landfills per category				**Has Gas Inspection Report** Number of landfills per category				**Has Gas Enforcement Action** Number of landfills per category				**Has Surface Water Action** Number of landfills per category			
	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination
0–4.9	19	5	5	8	3	4	1	5	8	3	2	6	2	0	0	0	6	2	0	4
5–99.9	67	19	20	19	22	4	6	12	39	7	9	13	13	2	0	6	17	6	0	5
100 or more	42	10	6	4	7	3	0	3	19	3	1	3	7	0	0	1	6	0	1	2

Observations From Quantitative Data Review (Table 5-H)

Combination landfills are more common in areas of relatively shallow groundwater than in areas of deep groundwater.

For active and inactive landfills, sites with more shallow groundwater tend to have a higher relative occurrence of "Has Surface Water Action." This trend supports the findings in Section 4.7.

5.3.3 Results and Observations: Average Annual Precipitation

Table 5-I: Summary of Environmental Performance and Landfill Site Characteristic Data for Active, Inactive, Closed, and Combination Landfills by *Average Annual Precipitation*

Landfill Site Characteristic					Environmental Performance Variables															
***Average Annual Precipitation* Categories (Inches)**	**Number of Landfills in Study**				**In Corrective Action** Number of landfills per category				**Has Gas Inspection Report** Number of landfills per category				**Has Gas Enforcement Action** Number of landfills per category				**Has Surface Water Action** Number of landfills per category			
	Active	**Inactive**	**Closed**	**Combination**	**Active**	**Inactive**	**Closed**	**Combination**	**Active**	**Inactive**	**Closed**	**Combination**	**Active**	**Inactive**	**Closed**	**Combination**	**Active**	**Inactive**	**Closed**	**Combination**
0–8.9	44	13	7	5	4	4	3	1	16	5	2	2	0	0	0	1	3	1	0	0
9–24.9	69	12	16	24	22	3	5	19	44	6	8	19	22	2	0	6	18	2	1	10
25 or more	15	9	8	2	6	4	0	0	6	2	1	1	0	0	0	0	8	5	0	1

Observations From Quantitative Data Review (Table 5-I)

Combination landfills are more common in areas of with between 9 and 24.9 inches of average annual precipitation.

With the exception of closed sites, landfills with greater average annual precipitation have a higher relative occurrence of "Has Surface Water Action." With the exception of closed and combination sites, landfills with greater average annual precipitation have a higher relative occurrence of "In Corrective Action."

5.3.4 Results and Observations: Liner Type

Table 5-J: Summary of Environmental Performance and Landfill Site Characteristic Data for Active, Inactive, Closed, and Combination Landfills by *Liner Type*

Landfill Site Characteristic					Environmental Performance Variables																
***Liner Type* Categories**	**Number of Landfills in Study**				**In Corrective Action** Number of landfills per category				**Has Gas Inspection Report** Number of landfills per category				**Has Gas Enforcement Action** Number of landfills per category				**Has Surface Water Action** Number of landfills per category			
	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination	Active	Inactive	Closed	Combination
Fully Subtitle D	4	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0
Fully Lined, Partially non-Subtitle D	9	0	2	1	3	0	1	1	4	0	2	1	2	0	0	1	2	0	0	0
Partially Unlined	42	3	4	21	14	1	3	14	28	2	3	14	10	1	0	4	11	1	0	6
Fully Unlined	73	31	25	9	14	10	3	5	32	11	6	7	10	1	0	2	15	7	1	5

Observations From Quantitative Data Review (Table 5-J)

Combination sites are more likely than sites with any other liner type to be partially. Inactive sites are more likely than sites with any other liner type to be fully unlined.

5.3.5 Results and Observations: Final Cover Type

Table 5-K. Summary of Environmental Performance and Landfill Site Characteristic Data for Active, Inactive, Closed, and Combination Landfills by *Final Cover Type*

Landfill Site Characteristic					Environmental Performance Variables															
***Final Cover Type* Categories**	**Number of Landfills in Study**				**In Corrective Action** Number of landfills per category				**Has Gas Inspection Report** Number of landfills per category				**Has Gas Enforcement Action** Number of landfills per category				**Has Surface Water Action** Number of landfills per category			
	ctive	nactive	losed	ombination	ctive	nactive	losed	ombination	ctive	nactive	losed	ombination	ctive	nactive	losed	ombination	ctive	nactive	losed	ombination
Fully Covered	0	10	31	7	0	3	8	6	0	2	11	7	0	0	0	1	0	2	1	3
Partially Covered	14	0	0	16	5	0	0	8	8	0	0	8	7	0	0	4	6	0	0	4
Fully Uncovered	114	24	0	8	27	8	0	6	58	11	0	7	15	2	0	2	23	6	0	4

Observations From Quantitative Data Review (Table 5-K)

All closed landfills are fully covered. All active landfills are at least partially uncovered. This data supports the implicit relationship between the *Final Cover Type* and *Site Status* variables.

With the exception of "Has Gas Enforcement Action," fully covered closed sites have a lower relative occurrence of each environmental performance variable than fully covered inactive sites.

5.3.6 <u>Summary of Observations From Quantitative Data Review For the Five Landfill Site Characteristics</u>

A look at all of the observations for the five landfill site characteristics leads to the following key observations about active, inactive, closed, and combination landfills:

- Landfills that are less than 10 acres in permitted disposal area are either active, inactive, or closed, but not a combination of these site statuses.
- Landfills of this size generally consist of one WMU, rather than consisting of multiple WMUs.
- Combination landfills are more common in areas of relatively shallow groundwater and moderate average annual precipitation.
- Combination sites are more likely to be partially unlined than any other *Liner Type.*

- As stated in Section 4, combination sites are generally larger and consist of multiple WMUs built at different times. This has resulted in a wider range of liner types and site statuses.
- With the exception of closed sites, landfills with greater average annual precipitation have a higher relative occurrence of "Has Surface Water Action." With the exception of closed and combination sites, landfills with greater average annual precipitation have a higher relative occurrence of "In Corrective Action." These observations lead to the conclusion that with more rain, there is more potential for erosion and more potential for leachate generation.
- All closed landfills are fully covered. All active landfills are at least partially uncovered. This data supports the implicit relationship between the *Final Cover Type* and *Site Status* variables.

6 Conclusions

This section presents the key findings from the analyses summarized in Sections 2 through 5. As a whole, MSW landfills in California are diverse in size, setting, and design but similar in function. Even though the sites vary widely in their characteristics, this study has identified common characteristics that, as a trend, can be associated with environmental compliance concerns as defined in Section 3.

6.1 Key Findings of Landfill Site Characteristics

6.1.1 Landfill Variety

As described in Section 2, the 224 landfills contained within this study vary greatly. The landfills vary in permitted disposal area from 1 acre to 800 acres. The permitted volume ranges from 2,100 cubic yards to approximately 185 million cubic yards. The landfills are permitted to accept from 1 ton of MSW per day to over 13,000 tons per day.

Some landfills date back to the 1910s and 1920s, and others are less than 15 years old. Several newer landfills are completely lined with Subtitle D-compliant liners, while many older sites are completely unlined, as allowed by the regulations; still other sites have a variety of lined and unlined WMUs built at different times.

6.1.2 Typical California Landfill

Based on the results of the statistical evaluation of the database, the typical MSW landfill in California at the time of the study can be described as shown in Table 5-A (Section 5.1). The typical landfill is publicly owned, active, located inland, either fully unlined or partially unlined (in the case of active sites), fully uncovered, and has no gas collection system. The typical landfill has a permitted disposal area of 55.5 acres and a permitted disposal volume 2.7 million cubic yards. The typical landfill is underlain by sand and/or gravel, has a minimum depth to underlying groundwater of 34.5 feet, and receives an average annual precipitation of 16 inches.

6.1.3 Remaining Capacity

The permitted remaining capacity for the landfills during the timeframe of the study ranged from approximately 2,000 cubic yards to approximately 95 million cubic yards. For the entire state, the total remaining capacity was approximately 1.2 billion cubic yards, which equates to approximately 35 cubic yards per person. This is roughly equivalent to a cube that is 10 feet by 10 feet by 10 feet.

In general, California's remaining capacity for the time frame of the study was concentrated around the population centers (may include surrounding counties) of Los Angeles, San Francisco, Sacramento, and San Diego.

Based on the information gathered for the period from January 1, 1998, to December 31, 2001, the following nine counties had no remaining MSW capacity: Alpine, Mendocino, Modoc, Nevada, San Francisco, Sutter, Tehama, and Trinity. Between 2001 and the date of this report, additional landfills have closed or become inactive. This created an additional three counties with zero remaining capacity; Del Norte, Humboldt, and Tuolumne.

This closure pattern suggests that, increasingly, portions of primarily rural California cannot meet the landfill needs of their residents without hauling out of county or to neighboring states. Often, smaller, rural, county-owned landfills have closed and waste streams have been diverted to larger, centralized landfills.

6.2 Key Findings of Environmental Performance Analyses by Landfill Site Characteristics

Through the screening analyses conducted in this part of the study, site characteristics were analyzed with respect to the environmental performance variables. As a result, common characteristics were identified that were correlated to environmental performance or compliance problems. While a particular site characteristic may be more common among sites with certain characteristics, it does not necessarily mean that the site characteristics were the underlying cause for the actions taken by the regulators, but only that a correlation exists.

As described in Section 7, Phase II of the study will involve detailed analyses of individual sites to better understand the underlying reasons that a landfill is not in compliance and if it is related to current regulation.

6.2.1 Sites Most Likely to be in Corrective Action

The results of the statistical analysis presented in Section 4 demonstrate that sites most likely to be in corrective action or to have water-related cleanup and abatement orders are larger, located in urban areas, at least partially unlined, and located in areas of higher-than-average precipitation. These sites also tend to be privately owned and have landfill gas collection systems.

In contrast, small, rural, unlined sites in dry climates tend to have a lower occurrence of corrective action or water-related cleanup and abatement orders. These sites also tend to be publicly owned and are not required to have landfill gas collection systems.

These findings suggest that if all else is equal, a larger volume of waste spread over a larger area with higher precipitation results in a higher potential for a release into groundwater.

These larger, urban sites may tend to be more intensely monitored and attract greater regulatory scrutiny, thus leading to a higher relative occurrence of corrective action measures and cleanup and abatement orders. However, the data collected in this study can neither support nor refute this hypothesis.

6.2.2 Sites Most Likely Have Surface Water Action

The statistical analyses demonstrate that landfills in drier climates tend to have fewer surface water compliance issues, including leachate seeps and excessive erosion. It is logical to conclude that greater precipitation leads to greater potential for both erosion and leachate generation.

The analyses also show that sites that have undergone closure have a significantly lower occurrence of surface water actions. This suggests that construction of an approved final cover system can reduce the potential for surface water impacts.

6.2.3 Sites Most Likely to Have Air Quality and Gas Actions

Larger urban landfills that are greater than 60 years old, with higher annual precipitation, a combination of liner types, and that are partially closed are more likely to have landfill gas violations or notices to comply than other sites.

These findings suggest that if all else is equal, a larger volume of waste in areas of higher precipitation results in more landfill gas with a higher potential for gas compliance issues.

These larger, urban sites may tend to be more intensely monitored and attract greater regulatory scrutiny, thus leading a higher relative occurrence of gas-related violations. However, the data collected in this study can neither support nor refute this hypothesis.

6.3 Key Findings Based on Non-Quantified Observations

In addition to the quantified results presented above, a number of non-statistical observations were made in the course of the study and are described in this section.

6.3.1 Inconsistency Among Regulatory Agencies

One primary difficulty stems from the fact that the three primary regulatory agencies (EAs, RWQCBs, and AQMDs/APCDs) regulate and oversee the landfills differently. These differences are necessitated by the goals of each agency.

The EA regulates the landfills based on MSW operational units–generally on a site-wide basis. The RWQCBs regulate the landfills based on individual WMUs. EAs do not recognize the individual WMUs that may comprise the landfill. All of the information is kept for the "whole" site and is not broken down into individual WMUs. For example, information on capacity, compliance, cover type and site status is reported for the whole landfill and not broken down to specific WMUs. As a result, it is difficult to determine where a problem with performance or compliance has occurred at a landfill. Also, there are cases where two adjacent operational units are regulated separately as individual landfills, when they should be regulated as one landfill.

RWQCBs issue site-wide permits that can include both MSW and non-MSW WMUs (for example Class II surface impoundments). For purposes of this study, environmental performance and compliance records for each site were determined for MSW WMUs and did not include the non-MSW WMUs.

The AQMDs/APCDs regulate the landfills primarily based on the equipment in operation. In some cases, there are adjoining landfills with shared gas collection systems. For purposes of this study, performance and compliance issues then become difficult to assign to one landfill vs. the other. As a result, it was difficult to determine which landfill actually had a problem with performance or compliance.

Additionally, within each type of agency, there are differences in the information available. Even seemingly simple pieces of data can become complex. As an example, the EAs issue a SWFP for each landfill that lists, among other things, the design capacity of the site. However, this entry may a have a range of meanings depending on the landfill. In some cases, it refers to the total volume of the landfill as measured from the base grades to the final grades. In others it refers to the actual MSW volume (total airspace minus daily cover and final cover volumes). Still others refer to the remaining capacity, rather than total capacity.

These observed inconsistencies most likely have little, if any, effect on the enforcement of the regulations for any given site. All parties involved presumably understand the site-specific requirements. The difficulty comes only when comparing a group of sites where these differences affect the consistency of the data. In a study such as this one, a cross-media evaluation becomes increasingly difficult with these types of added complexity.

7 Recommendation of 40 MSW Landfills for Phase II of Study

7.1 Introduction

This section contains a list of 40 MSW landfills taken from the original 224 MSW landfills and recommended by GeoSyntec for Phase II of the study, the assessment of regulatory effectiveness. GeoSyntec selected 37 sites based on their general site characteristics and environmental performance. Additionally, the CIWMB identified three sites that might be impacted by regulations pertaining to very low waste acceptance levels that delay or avoid closure ("trickling waste") (27 CCR section 21110(b). GeoSyntec included these sites in the list of 40 landfills.

In addition to the 40 MSW landfills identified for assessment of regulatory effectiveness, the Phase II portion of the study will also include 13 MSW landfills that closed prior to 1993. The addition of these 13 landfills allows the assessment of regulatory effectiveness to be more complete by providing a longer closure period for review. The 13 landfills were selected by CIWMB staff working with staff from the SWRCB and ARB, and consist of the following sites:

1. Mission Canyon (Unit 1) (Canyons 1-3)—Los Angeles County
2. Mission Canyon (Unit 2) (Canyons 4-7)—Los Angeles County
3. Mission Canyon (Unit 3) (Canyon 8)—Los Angeles County
4. Coastal/Santa Clara Landfill—Ventura County
5. East Third Avenue Landfill—San Mateo County
6. Adelanto Disposal Site—San Bernardino County
7. Madrone Landfill—Santa Clara County
8. Old Mount Shasta Dump—Siskiyou County
9. South Chollas Sanitary Landfill—San Diego County
10. Ballard Canyon Road—Santa Barbara County
11. Coyote Canyon Sanitary Landfill—Orange County
12. Buckeye Disposal Site—Shasta County
13. McCourtney Road Landfill —Nevada County

7.2 Forty Landfills Recommended for Further Study

The 40 landfill from the Task 2 database selected for Phase II are shown in Table 7A. Also included in this table are the site characteristics employed in making the selection.

Table 7-A: Phase II Study Site List

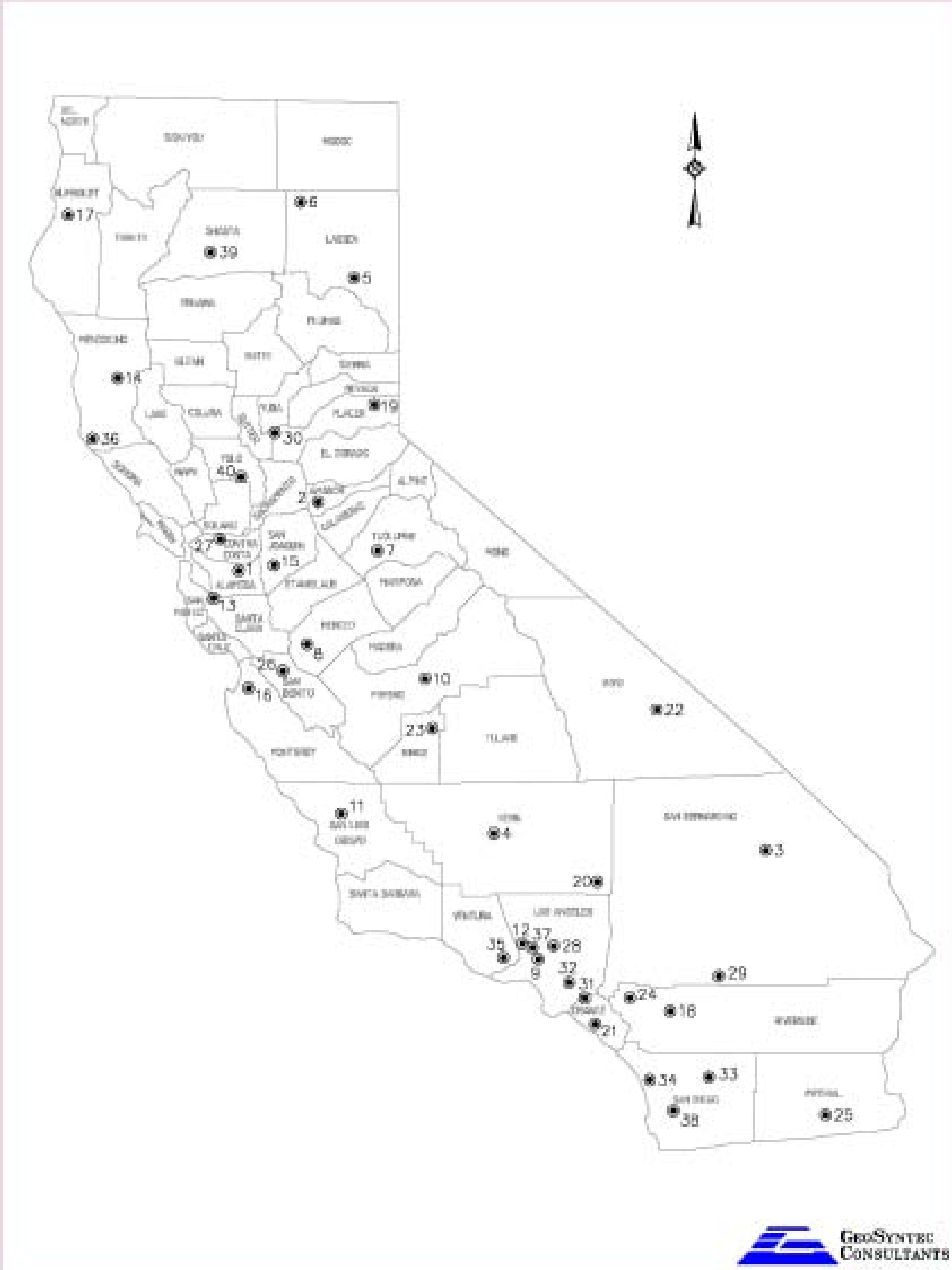
	Landfill Name and County	Vertical Expansion Over Unlined Unit	Fully Subtitle D or Alternative Liner	"Typical" California MSW Landfill	Gas Extraction System	Gas To Energy System	Bioreactor, Leachate/Condensate Recirculation	Mechanical Pre-treatment	Closed with GM cap	Closed With GCL Cap	Closed With Monofill or ET Cover	Title 27 Prescriptive Cover	Trickling Waste Site
1	Altamont Landfill and Resource Recovery Facility (Alameda County)				X	X							
2	Amador County Landfill/Buena Vista Class II Landfill (Amador County)			X									
3	Baker Refuse Disposal Site (San Bernardino County)										X		
4	Bakersfield Metropolitan (Bena) Sanitary Landfill (Kern County)												
5	Bass Hill Landfill (Lassen County)			X									
6	Bieber Landfill (Lassen County)									X			
7	Big Oak Flat Landfill (Tuolumne County)												X
8	Billy Wright Disposal Site (Merced County)												
9	Bradley Landfill West and West Extension (Los Angeles County)				X	X							
10	Chateau Fresno Landfill (Fresno County)				X				X				
11	Chicago Grade Landfill (San Luis Obispo County)	X			X	X						X	
12	Chiquita Canyon Sanitary Landfill (Los Angeles County)				X						X		
13	City of Palo Alto Landfill (Santa Clara County)				X	X							
14	City of Willits Disposal Site (Mendocino County)								X				
15	Corral Hollow Landfill (San Joaquin County)				X							X	

	Landfill Name and County	Vertical Expansion Over Unlined Unit	Fully Subtitle D or Alternative Liner	"Typical" California MSW Landfill	Gas Extraction System	Gas To Energy System	Bioreactor, Leachate/Condensate Recirculation	Mechanical Pre-treatment	Closed with GM cap	Closed With GCL Cap	Closed With Monofill or ET Cover	Title 27 Prescriptive Cover	Trickling Waste Site
16	Crazy Horse Sanitary Landfill (Monterey County)				X	X							
17	Cummings Road Landfill (Humboldt County)				X								X
18	Double Butte Sanitary Landfill (Riverside County)				X								
19	Eastern Regional Landfill (Placer County)				X							X	
20	Edwards AFB Main Base Sanitary Landfill (Kern County)							X					
21	Frank R. Bowerman (Orange County)				X								
22	Furnace Creek Landfill (Inyo County)										X		
23	Hanford Sanitary Landfill (Kings County)				X					X			
24	Highgrove Sanitary Landfill (Riverside County)				X						X		
25	Holtville Disposal Site (Imperial County)												X
26	John Smith Road Class III Landfill (San Benito County)			X	X								
27	Keller Canyon Landfill (Contra Costa County)		X		X		X						
28	Lopez Canyon Sanitary Landfill (Los Angeles County)				X	X					X	X	
29	Morongo Disposal Site (San Bernardino County)									X			
30	Norcal Waste Systems Ostrom Road Landfill (Sutter County)		X										
31	Olinda Alpha Sanitary Landfill (Orange County)				X	X							

	Landfill Name and County	Vertical Expansion Over Unlined Unit	Fully Subtitle D or Alternative Liner	"Typical" California MSW Landfill	Gas Extraction System	Gas To Energy System	Bioreactor, Leachate/Condensate Recirculation	Mechanical Pre-treatment	Closed with GM cap	Closed With GCL Cap	Closed With Monofill or ET Cover	Title 27 Prescriptive Cover	Trickling Waste Site
32	Puente Hills Landfill (Los Angeles County)				X	X							
33	Ramona Landfill (San Diego County)			X	X								
34	San Marcos Landfill (San Diego County)	X			X	X			X				
35	Simi Valley Landfill & Recycling Center (Ventura County)	X			X								
36	South Coast Solid Waste Site (Mendocino County)												
37	Sunshine Canyon Sanitary Landfill County Extension (Los Angeles County)		X		X								
38	Sycamore Sanitary Landfill (San Diego County)				X	X							
39	West Central Landfill (Shasta County)												
40	Yolo County Central Landfill (Yolo County)				X	X	X						

The geographic distribution of the sites is shown in Figure 7.1. The number adjacent to each site marker corresponds to the site number listed in Table 7-A. Four landfills—West Central Landfill, Billy Wright Disposal Site, South Coast Solid Waste Site, and Bakersfield Metropolitan (Bena) Sanitary Landfill—were included to provide a more representative geographic distribution. Figure 7.1 shows that the sample of 40 sites appears relatively well distributed throughout the state.

Figure 7.1 Phase II Study Map



These 40 sites, along with the 13 sites closed prior to 1993, are the basis for Phase II of the Landfill Facility Compliance Study.

Appendix A: A Brief Overview of Non-MSW Landfills

A.1 Introduction

The purpose of this section is to advise the reader of another set of solid waste landfills that are not addressed by the contracted study. These are solid waste landfills that do not accept MSW. Each of the sites within the 224-landfill inventory accepted MSW. The non-MSW landfills were not included in the Task 2 database inventory and were not included in the screening analyses presented in Sections 4 and 5. However, the following section provides a brief overview of some of the non-MSW sites.

A.2 Non-MSW Waste Disposal Sites

As part of the scope of work to provide a brief overview of non-MSW landfills, GeoSyntec collected a limited amount of data on some non-MSW California disposal sites. At the beginning of this project, the CIWMB, working with staff from the SWRCB and ARB, identified eight non-MSW sites to be included in the overview. These landfills range in size from 2 to 160 acres. The sites are listed in Table A-A.

Table A-A Paritial List of Non-MSW Waste Disposal Sites

Disposal Site	County
Ascon Landfill (Wilmington)	Los Angeles
Desert Valley Monofill	Imperial
Geothermal, Inc. Facility	Lake
I-580 Freeway Class II Landfill	Contra Costa
McKittrick Waste Treatment Site	Kern
Twin Bridges Class II Landfill	Shasta
USAF March AFB Landfill	Riverside
USAF Norton AFB Landfill	San Bernardino

As indicated in Table A-A, these eight landfills are located throughout California. As such, the landfills fall in a wide range of settings. Social settings vary from rural to urban. Annual precipitation ranges from 3 inches to 44 inches, and physical settings range from inland to desert.

A.3 Waste Types

The waste types permitted for disposal in these eight disposal sites vary from site to site. Permits for each site (Waste Discharge Requirements and Solid Waste Facilities Permit) indicate allowable waste types and prohibited waste types. Collectively, permits for these landfills authorize for disposal the following waste types:

- Ash.
- Demolition debris.
- Primary clarifier solids.
- Carbonates.

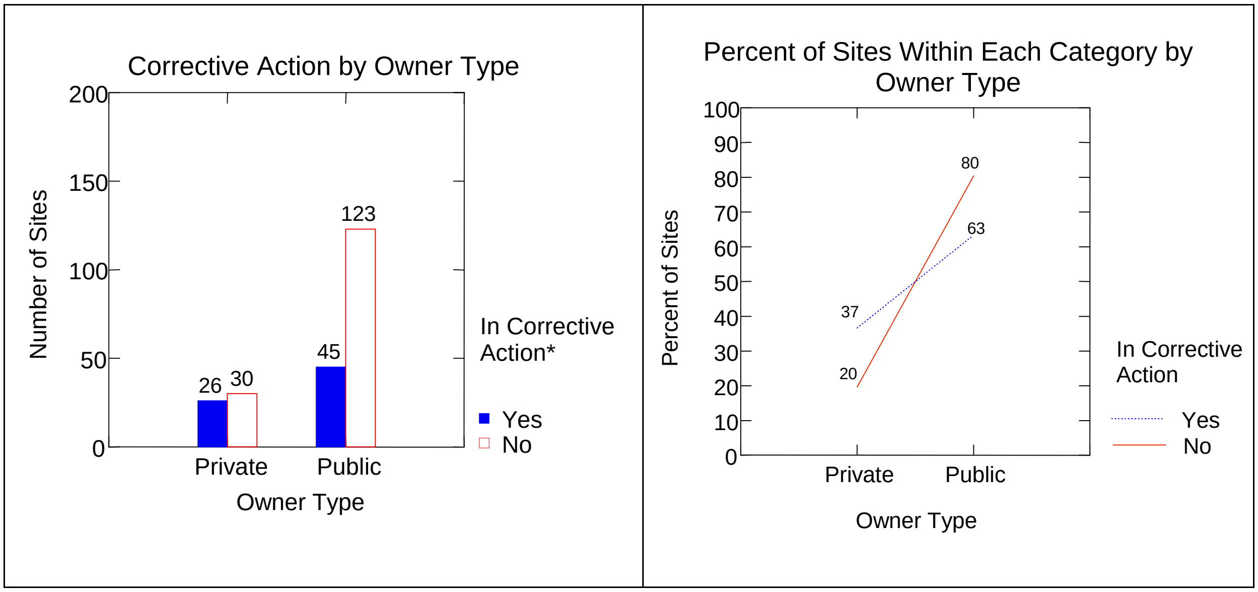
- Filter cake.
- Drilling mud.
- Drilling cuttings.
- Soil-contaminated geothermal brines.
- Nonhazardous petroleum-contaminated soil.
- Fiber and wood residue.
- Industrial wastes.
- Concrete and asphalt rubble.
- Dihydrogen sulfide abatement sludge.

Appendix B-1: Statistical Analysis Processes Used in Study and General Explanations

B-1.1 Evaluation of Categorical Independent Variables

In order to identify possible correlation between select independent and dependent variables, it is useful to first conduct a simple graphical analysis of the data as part of the exploratory data analysis (EDA). The graphical results of the EDA are provided in Appendices B-2 though B-5 as part of the summary of results. As an example of the approach taken, this section considers the relationship between landfill ownership type (private or public) and the variable “In Corrective Action.” (based on RWQCB monitoring status). Figure B-1-1 displays both the frequency (bar chart on the left) and relative percentage of each independent variable category (line chart on the right) as seen in Appendices B-2 through B-5.

Figure B-1-1. Graphical Analysis of Categorical Independent Variable



* In Appendices B-2 through B-5, the legend lists “In Corrective Action” or “Not in Corrective Action” instead of “In Corrective Action”/“Yes” or “No.”

The bar chart on the left displays the number of sites that are and are not in the category "In Corrective Action" grouped by either private or public owner types. The chart provides some indication that there appears to be a difference in the proportion of privately owned sites in corrective action when compared with publicly-owned sites. However, any potentially significant relationship between owner type and "In Corrective Action" cannot be determined based strictly on the counts displayed here, since there are many more public sites in the database.

The values displayed in the line chart on the right represent the distribution of the dependent variables with relation to the independent variables. As shown by the dashed line in this chart, privately owned sites make up approximately 37 percent of those in the "In Corrective Action" category, while publicly owned sites make up the remaining 63 percent. As shown by the solid line in this chart, privately owned sites make up approximately 20 percent of those not in the "In Corrective Action" category, while publicly owned sites make up the remaining 80 percent

Because there are many fewer privately owned sites than publicly owned sites, it is logical to expect that the private sites will make up a smaller percentage of each dependent variable category. However, as demonstrated by the difference in the slope of the two lines in this diagram, private sites make a greater relative contribution to the "In Corrective Action" response. The converse is true for public sites.

The EDA graphical results provide a preliminary assessment of the data, which assists with subsequent hypothesis testing and screening of results. However, without a more rigorous statistical analysis, it is unclear if the differences shown in these two charts are statistically significant.

B-1.2 Logistic Regression Analysis of Categorical Independent Variables

Logistic regression analysis seeks to use one or more independent variables to estimate the odds of one outcome occurring versus another, where the outcomes are discrete, categorical, dependent variables. The basic form of a logistic regression model is as follows:

$$LN\left(\frac{P_1}{P_2}\right) = \alpha + \beta X$$

where:

P_1 = probability of dependent variable category 1
P_2 = probability of reference dependent variable category 2
α = intercept constant
β = slope coefficient
X = independent (explanatory) variable

The form above is for a discrete dependent variable consisting of only two categories ("is dichotomous" or "binomial"), where the sum of the values P_1 and P_2 is equal to 1. It is clear from this to see that $P_2 = 1-P_1$. Logistic regression analysis may also be conducted for dependent variables divided into more than two discrete categories (the sum of all individual probabilities equal to 1), although interpretation of the results is often less intuitive. For the purposes of this report, only binomial logistic analysis was conducted. For example, each of the dependent variables was defined in terms of two possible outcomes.

There are a number of measures of the results of a logistic regression analysis. Here the results are interpreted using the odds ratio $\frac{P_1}{P_2}$, the bounds on the odds ratio, and the p-value. From the odds ratio, it is possible to quantify how much more or less likely outcome #1 (in this case, "In Corrective Action") is than outcome #2 (in this case, "Not in Corrective Action") for each independent variable category (in this case, "Private" or "Public"). For a binomial logistic regression, outcome #2 is considered the default, or reference value, of the dependent variable. The reference value is selected for each variable based on what would be considered the default value.

Like the dependent variable, the independent variable in the logistic regressions conducted as part of this study is discrete, and each of the variable categories is expressed in comparison to a reference category. In the example discussed here, the independent variable is divided into only two categories, with "Public" serving as the reference (the default or base value for the independent variable). The independent variable therefore takes a single value: $\frac{\text{Private}}{\text{Public}}$.

The reference category answers the question "More likely than what?" In this case, private sites may be more or less likely to be in the "In Corrective Action" category than public sites. Without identifying the independent variable categories in terms of a reference category, the resulting odds ratios would be meaningless.

All statistical analyses conducted in this study were generated using the SYSTAT 10 software. The Logit routine was used for logistic regression. A summary of the logistic regression output for *Owner Type* versus "In Corrective Action" is provided in Table B-1-A.

Table B-1-A: Example Binary Logit

$$LN\left[\frac{\Pr(\text{In Corrective Action})}{\Pr(\text{Not in Corrective Action})}\right] = -1.0055 + 0.86242\left(\frac{\text{Private}}{\text{Public}}\right)$$

Coefficient	Value	SE	t-ratio	p-value
Constant	-1.0055	0.17422	-5.77	0.0000
Private/Public	0.86242	0.31960	2.70	0.00697
Parameter	Odds Ratio		Upper 95% bound	Lower 95% bound
Private/Public	2.369		4.432	1.266

The "Constant" coefficient in the resulting model does not affect how the dependent and independent variables change in relation to one another, so the results for the constant are not relevant to analysis. The reported p-value for the Private/Public slope coefficient (β) indicates that the probability of this result occurring by chance is approximately 0.7 percent, so the result is considered significant (using a threshold of 5 percent or 0.05). This means that the result is significant at the 5 percent significance level (99.5 percent confidence).

The odds ratio is calculated by taking the exponent of the slope coefficient. In this example, the odds ratio is greater than one, indicating that it is *more likely* that the independent variable "Private/Public" is associated with outcome #1 ("In Corrective Action"). Because the independent variable is itself a ratio, the final result may be interpreted as follows:

> Based on the available data, private sites are **2.4 times more likely** to be in the category "In Corrective Action" than public sites.

Table B-1-B below provides an example of how the results shown above in Table B-1-1 are summarized in Appendices B-2 though B-5.

Table B-1-B: Sample Categorical Independent Variable Results

Summary Table of Results—Logistic Regression (Reference Dependent Variable is "Not in Corrective Action")					
Independent Variable Category	**Reference Value for Independent Variable**	**Probability**	**Odds Ratio**	**Upper 95 Percent Bound on Odds Ratio**	**Lower 95 Percent Bound on Odds Ratio**
Private	**Public**	**0.007**	**2.369**	**4.432**	**1.266**

The odds ratio is an estimated value computed by the model. The quality of the estimate is based on a number of factors, including sample size. A small sample size (n < 20) is unlikely to yield significant results unless the relationship between independent factor and dependent response is very strong. One method of evaluating the significance of the odds ratio is examination of the upper and lower bounds. The SYSTAT software uses a 95 percent confidence interval to evaluate the odds ratio (for example, the probability that the odds ratio falls within the range of the upper and lower bound is 95 percent). This confidence interval is consistent with the use of the 95 percent confidence interval for all analyses conducted in this study and is an appropriate level of significance for environmental data analysis.

If the lower bound is less than 1 but the upper bound is greater than 1, then the result is not considered significant. In these cases, the probability will also be greater than 0.05, another indication that the result is not significant.

If both the upper and lower bounds are less than 1 (the p-value will also be less than 0.05), then the odds ratio will also be less than 1. Interpretation of the results, therefore, is based on the inverse of the odds ratio and the corresponding upper and lower bounds. In the example displayed in Table B-1-B, various categories of *Physical Setting* are regressed against "In Corrective Action." The initial odds ratio was not considered significant for any of the independent variable categories; however, the inverse odds ratio revealed a significant relationship between desert sites and "In Corrective Action," compared to inland sites. To interpret the results, "In Corrective Action" is considered the reference dependent variable (instead of "Not in Corrective Action"), and the calculated odds ratio is expressed as follows:

Desert sites are approximately **3.7 times less likely** to be in corrective action than inland sites.

Table B-1-C: Interpretation of Inverse Odds Ratio

Summary Table of Results—Logistic Regression (Reference Dependent Variable is "In Corrective Action")					
Independent Variable Category	**Reference Value for Independent Variable**	**Probability**	**Odds Ratio**	**Upper 95 Percent Bound on Odds Ratio**	**Lower 95 Percent Bound on Odds Ratio**
High Desert	Inland	0.117	5.408	44.649	0.655
Desert	**Inland**	**0.001**	**3.681**	**8.188**	**1.655**
Alpine	Inland	0.235	2.254	8.616	0.589

Coastal	Inland	0.599	0.761	2.11	0.274
Estuarine	Inland	0.399	2.028	10.473	0.393

It is important to note that the logistic regression approach does not yield results that may be used to model possible outcomes, as might be done with linear regression. The odds ratio calculated for each independent variable is expressed in terms of the independent reference category (in this case, "Public"); therefore, the "odds" of a particular outcome (for example, "In Corrective Action") occurring is specific to the comparison being made. This becomes increasingly important for independent variables with more than two categories, since each reported odds ratio applies to only a subset of the entire sample.

Given this caveat, the simplest and most broadly applicable interpretation of results for the categorical independent variables is whether or not they indicate that a particular independent variable category yields a statistically significant result. A baseline or reference category is selected for each variable. Generally, the most common category is selected (for example, in Table B-1-C, the Inland category is the reference category because it is the most common *Physical Setting* category.) All of the remaining independent variable categories (such as *Desert, High Desert, Alpine*) are then compared against the reference category. Therefore, compared to those categories that do not exhibit a significant result, the significant category or categories may be assumed to exhibit a stronger correlation with the dependent variable. The magnitude of the odds ratio does indicate the strength of the relationship; however, the actual magnitude is typically less important than the significance of the relationship, and it is also less significant than whether the dependent variable is directly or inversely proportional to the independent variable.

B-1.3 Evaluation of Continuous Independent Variables

The logistic regression model is not applicable to independent variables that are continuous, unless they may be made discrete. To analyze continuous variables, an analysis of variance was used to determine whether the higher or lower range of the independent variable (for example, *Annual Precipitation*) is more closely associated with the different dependent variable outcomes (in this case, "In Corrective Action" or "Not in Corrective Action").

The most common two-sample hypothesis test is the independent-sample t-test, which assumes that both samples are drawn from normally distributed populations (the test also applies to appropriately transformed data sets). When the population distribution is not known, the one-sample Lilliefors test may be used to assess whether a sample is likely drawn from a normal or lognormal population. Application of the Lilliefors test to the continuous independent variables did not indicate that the variables are well represented by either normal or lognormal distributions.

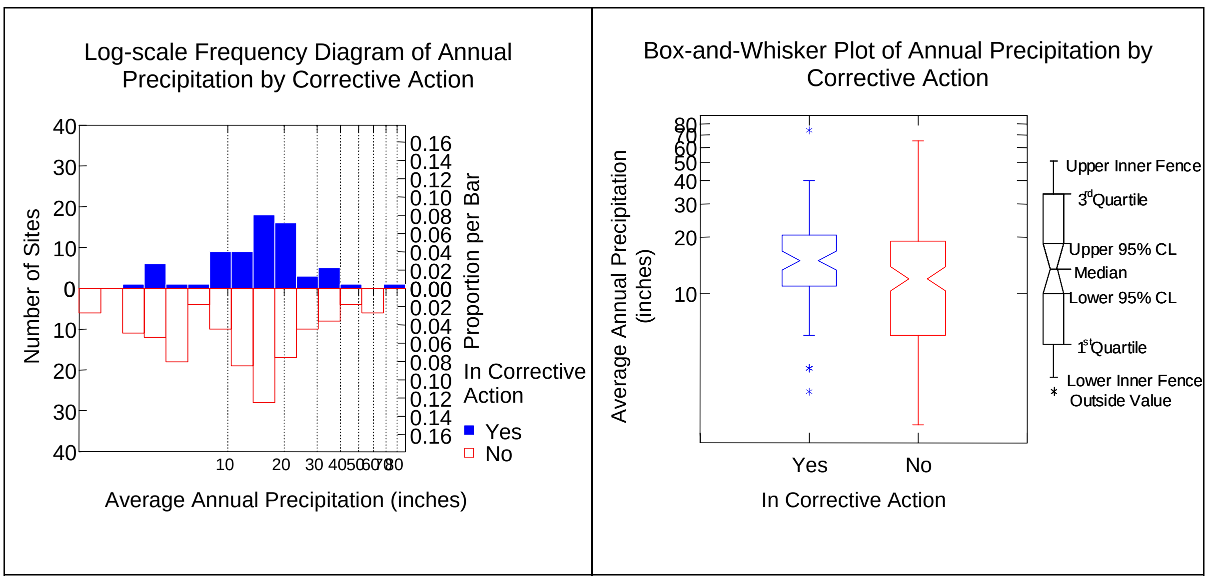
When the standard t-test is not applicable, a robust non-parametric alternative is the Kruskal-Wallis test, which like the t-test evaluates the probability that two or more samples are drawn from the same population (the two-sample form of this test is also referred to as the Mann-Whitney test). The Kruskal-Wallis test was conducted for the continuous independent variables, with the two dependent variable outcomes representing the two samples analyzed. For example, the "In Corrective Action" variable defines sites that are in the category "In Corrective Action" ("Yes" values) and sites that are not in the "In Corrective Action" category ("No" values). Table B-1-C displays an example output for *Annual Precipitation*, as it is summarized in Appendices B-2 through B-5.

Table B-1-C: Example Continuous Independent Variable Results

Summary Table of Results Kruskal-Wallis Analysis of Variance	
Independent Variable Category	**Probability**
Annual Precipitation	0.033

The Kruskal-Wallis test only indicates whether the difference in the two samples is statistically significant. It does not indicate which sample is greater—that is, which sample has a higher median value. This may be assessed by graphical analysis or by examining descriptive statistics (median values) for each sample. The box-and-whisker plot for the *Average Annual Precipitation* example provided on the right side of Figure B-1-2 reveals that precipitation at sites in the "In Corrective Action/Yes" category tend to be slightly greater than at sites in the "No" category. This helps to confirm what might be expected: sites that experience greater precipitation are more likely to have groundwater compliance issues. The histogram on the left side of Figure B-1-2 provides the relative size of each sample and some idea of their distribution. It appears that measured average annual precipitation at sites in the "In Corrective Action/Yes" category is more concentrated about the median value than at sites in the "No" category.

Figure B-1-2: Boxplot For Continuous Independent Variable



* In Appendices B-2 through B-5, the legend lists "In Corrective Action" or "Not in Corrective Action" instead of "In Corrective Action"/"Yes" or "No."